

EXHIBIT 26

Expert Report of Frank Gobas, Ph.D

Effect of Discharges of PCBs by the City of Spokane on Concentrations of PCBs in Fish of the Spokane River

City of Spokane v. Monsanto Co., et al.

No. 2:15-CV-0201-SMJ

Prepared for:

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Dallas, TX

October 10, 2019



Report by Dr. Frank Gobas

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Attachment A: Curriculum Vitae

Attachment B: List of References

Attachment C: Spokane River PCB Concentration Data Analysis: Technical Memorandum By Azimuth

ACRONYMS

CEPA	Canadian Environmental Protection Act
cfs	cubic feet per second
CLAM	Continuous low-level aqueous monitoring
COS	City of Spokane
CSO	Combined sewer overflow
CV	Curriculum vitae
d	day
dw	dry weight
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management System (Washington State)
EU	European Union
FAO	Food and Agricultural Organization (UN)
g	gram, one thousandth of a kilogram
GESAMP	UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
IAEA	International Atomic Energy Agency (UN)
ID	Idaho State
ID#	Identification (label or number)
IF	Impact factor
IMO	International Maritime Organization (UN)
IOC	Intergovernmental Oceanographic Commission (UNESCO)
kg	kilogram
km	kilometer, one thousand meters
K _{ow}	Octanol-water partition coefficient
L	liter
lb	pound
m	meter
mg	milligram, one millionth of a kilogram
MGD	Million gallons per day

mm	millimeter, one millionth of a meter
MS4	Municipal separate storm sewers
n	number, count
NRDA	Natural Resource Damage Assessments (US)
NSERC	National Science and Engineering Research Council (Canada)
OC	Organic carbon
PCBs	Polychlorinated biphenyls
pg	picogram, one quadrillionth of a kilogram
PGG	Pacific Groundwater Group
POC	Particulate organic carbon
POP	Persistent organic pollutant
ppb	parts per billion
ppm	parts per million
QA	Quality assurance
QC	Quality control
REACH	Registration, Evaluation, Authorization and Restriction of Chemical Substances (EU)
RM	River mile
RPWRF	Riverside Park Water Reclamation Facility (City of Spokane)
s	second
SARA	Species at Risk Act (Canada)
SD	Standard deviation
SETAC	Society of Environmental Toxicology and Chemistry
SFU	Simon Fraser University
SPE	Solid phase extraction disks
SPMD	Semipermeable membrane device
SRRTTF	Spokane River Regional Toxics Taskforce
TMDL	Total maximum daily load
TMF	Trophic magnification factor
TOC	Total organic carbon
TSCA	Toxic Substances Control Act
TSS	Total suspended solids

UN	United Nations
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service
WA	Washington State
WDOH	Washington Department of Health
WHO	World Health Organization (UN)
WMO	World Meteorological Organization (UN)
ww	wet weight
WWTP	Wastewater treatment plant
µg	microgram, one billionth of a kilogram

1. QUALIFICATIONS

This section provides an overview of the qualifications of Dr. Gobas for providing opinions on the fate of PCBs in the Spokane River. A detailed account of his contributions to the science and education of hydrophobic organic contaminants in the environment are listed in his CV, which is included in **Attachment A**.

1.1. Education

Dr. Gobas received a B.Sc. from the Free University of Amsterdam, a M.Sc. in Environmental Chemistry and Toxicology from the University of Amsterdam, and a Ph.D. in Chemical Engineering and Applied Chemistry from the University of Toronto. He is now a full professor in the School of Resource & Environmental Management and an associate member of the Department of Biological Sciences at Simon Fraser University (SFU).

1.2. Area of Research

Dr. Gobas is an environmental toxicologist with expertise in environmental chemistry, chemical engineering, biology and policy analysis. Dr. Gobas' research focuses on the environmental behavior and effects of pollutants. His research investigates how pollutants are taken up by wildlife and humans; how pollutants behave in food webs and ecosystems; how pollutants cause health effects; and how contaminated environmental systems can be remediated. His research involves laboratory studies, field studies, simulation modelling and policy analysis.

1.3. Professional Experience & Scientific Publications

Dr. Gobas has published approximately 200 scientific publications, mostly in high quality international scientific journals including Science (impact factor (IF=37), Environmental Science and Technology (IF=6.2), Science of the Total Environment (IF=4.9) and Water Research (IF=7.1). He has provided approximately 300 invited presentations at scientific, regulatory and public meetings. He has been a member of the Science Advisory Board of the USEPA, Director of the Science Advisory Board for Contaminated Sites in British Columbia and served for 6 years as a Member of the UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), which is the scientific advisory body of the IMO, FAO, UNESCO, IOC, WMO, WHO, IAEA, UN and UNEP on global marine environmental protection. He has provided expert advice to Environment Canada (related to the Canadian Environmental Protection Act [CEPA]), Fisheries and Oceans Canada (related to the Species at Risk Act [SARA]) and the recovery of the Southern Resident Killer Whale

population), the European Chemical Agency (related to REACH legislation), the USEPA (regarding water quality criteria and pesticide use), the International Council of Chemical Association (regarding chemical evaluation and risk assessment), the European Chemical Industry Council (regarding research priorities), the Japanese EPA (regarding bioaccumulation criteria) and several Natural Resource Damage Assessments (NRDAs) in the US, including the Hudson River, the Housatonic River and San Francisco Bay (for 21 years). Dr. Gobas wrote the Pathway report for the NRDA for the Hudson River together with Dr. Lisa Rodenburg on behalf of the Hudson River Natural Resources Trustees. Dr. Gobas has served on the editorial boards of 4 scientific journals and was the editor of the Bioaccumulation section of SETAC Globe. He has organized many workshops, conferences and sessions at conferences. His research has attracted approximately \$6.7 million dollars in research funding from a variety of sources including NSERC, various industry associations and government agencies in Canada and the US. Details regarding Dr. Gobas' experience can be found in [Attachment A](#).

Dr. Gobas was an expert witness in the 2011 Canada Board of Review of Decamethylcyclopentasiloxane (D5).

A selected list of scientific publications is provided in Dr. Gobas' CV in [Attachment A](#).

1.4. Deposition and Trial Testimony in Past Four Years

Dr. Gobas has not been deposed or provided trial testimony in the past 4 years.

2. PROBLEM STATEMENT

The Spokane River is subject to inputs of PCBs from a variety of sources. PCBs discharged into the Spokane River have caused concentrations of PCBs in certain fish species to exceed limits for the safe consumption of fish from the Spokane River by human consumers.

The City of Spokane is responsible for the operation of three facilities/systems that discharge PCBs into the Spokane River. These facilities are (i) the City of Spokane Riverside Park Water Reclamation Facility (RPWRF; formerly Waste Water Treatment Plant [WWTP]); (ii) the City of Spokane MS4 stormwater basins¹; and (iii) the City of Spokane combined sewer overflow

¹ There are 12 MS4 stormwater basins: Superior, Cochran, Union, Riverton, Washington, Greene, Hollywood, Howard, Mission, Lincoln, Rifle, and Kiernan. These are collectively referred to as MS4 basins in this report.

(CSO) outfalls². The City of Spokane RPWRF discharges to the Spokane River at river mile (RM) 67.4. The City of Spokane MS4 stormwater basins and CSO outfalls discharge to the Spokane River between Upriver Dam (RM 80.2) and Nine Mile Dam (RM 58.1). Over the past decade, the City of Spokane made several modifications to these facilities to reduce the discharge of PCBs into the Spokane River (e.g. CSO improvement projects, and implementing best management practices (BMPs) to reduce PCBs in stormwater). The City of Spokane is planning additional modifications to further reduce discharges of PCBs into the Spokane River with the goal to achieve concentrations of PCBs in fish of the Spokane River that do not harm human consumers of fish.

This opinion addresses two questions, namely:

1. How have reductions of PCB discharges by the City of Spokane, implemented after the Washington State Department of Ecology's (Ecology) 2003-2007 PCB source assessment (published April 2011), affected present-day concentrations of PCBs in fish of the Spokane River?
2. How will further reductions of PCB discharges by the City of Spokane, projected to 2030, affect the concentrations of PCBs in fish of the Spokane River in the future?

To address these questions, several analyses were conducted. The first analysis involved analyzing PCB discharge rates from the facilities operated by the City of Spokane as well as those originating from other sources in the Spokane River watershed. The objective of this analysis was to (i) establish the actual discharge rates of PCBs by the City of Spokane; (ii) document the change in PCB discharge rates by the City of Spokane over time as a result of remediation efforts at the City of Spokane facilities; and (iii) determine the contribution of PCB discharges by the facilities operated by the City of Spokane to the total input of PCBs into the Spokane River resulting from all known sources.

The second analysis involved compiling and analyzing information on the concentrations of PCBs in water, sediments and fish of the Spokane River. Changes in the concentrations of PCBs over time were investigated to determine the effect of remedial efforts at the City of Spokane facilities since 2003-2007 to present on the concentrations of PCBs in fish of the Spokane River.

² Includes 20 CSO outfalls numbered: 002, 006, 007, 010, 012, 014, 015, 016B, 019, 020, 022B, 023, 024, 025, 026, 033, 034, 038, 041, 042, plus a RPWRF CSO bypass.

The third analysis involved combining information on the discharge rates of PCBs from the City of Spokane facilities and with the measured concentrations of PCBs in fish of the Spokane River to determine the concentrations of PCBs in fish of the Spokane River that can be expected as a result of past and on-going remedial efforts.

In this opinion, I document the sources of information and methods used in each analysis in **Section 6.2**, with more detailed information in **Attachment B - References** and **Attachment C – Spokane River PCB Concentration Data Analysis**. In **Section 6.3**, I discuss the results of each analysis and present answers to the two questions stated in the problem statement.

3. SUMMARY OF OPINIONS

The reductions in PCB discharges by the City of Spokane have reduced concentrations of PCBs in water, sediment, and fish in the Spokane River by between 7.1 and 12.1% since the 2003-2007 period.

Based on my analysis, the reductions of PCB discharges at three City of Spokane facilities between the 2003-2007 period and 2018 have caused a 7.1 to 12.1% reduction in the combined PCB inputs downstream of the City of Spokane RPWRF, MS4 stormwater basins and CSO outfalls. Concentrations of PCBs in water, sediment and fish respond to reductions in total PCB inputs in a linear (or proportional) fashion; therefore, concentrations of PCBs in water, sediments and fish can be expected to have been reduced from 2003-2007 levels by 7.1 to 12.1%, depending on the location in the River, as a result of PCB emission reduction initiatives at the City of Spokane facilities.

From measurements of the concentrations of PCBs in water, sediment and fish in the Spokane River, it can be concluded that concentrations of PCBs in water, sediments and fish of the Spokane River have declined in various sections of the River between 2003-2007 and 2018. This is likely due to PCB discharge reductions by the City of Spokane facilities and other remediation activities in the Spokane River, notably the capping of PCB contaminated sediments near Upriver Dam/Donkey Island (near RM 80 to 84).

Should Spokane implement the future remediation measures proposed in the Expert Report of Michael Baker International (2019), I expect concentrations of PCBs in water, sediments and fish to decline by up to 17.4%, relative to the 2003-2007 period.

Downstream of the facilities of the City of Spokane, future concentrations of PCBs in water, sediment and fish can be expected to fall by a further 4.1 to 5.9% from 2018 levels (which is a 3.8 to 5.2% drop relative to 2003-2007 levels), if the smaller reductions in PCB discharges

are achieved, or by 4.2 to 6.0% from 2018 levels (which is 3.9 to 5.3% drop relative to 2003-2007 levels), if the higher reductions in PCB discharges are achieved, in response to planned PCB emission control initiatives at the City of Spokane facilities. These reductions in concentrations are due to expected reductions in PCB discharges, of between a 4.1-fold (for a “low treatment” option) to 4.7-fold (for a “high treatment” option), from the City of Spokane facilities, relative to present-day discharges.

Prediction of the concentrations of PCBs in fish of the Spokane River after PCB emission control initiatives at the City of Spokane facilities are implemented show that, in sections of the River affected by PCB discharges from the City of Spokane facilities, the planned treatment at the City of Spokane facilities will reduce concentrations of PCBs in fish downstream of the City of Spokane facilities from the latest levels measured in 2012 by somewhere between 4.2 to 7.2%.

When future (2030) projected loadings of PCBs are compared to baseline loadings of PCBs, concentrations of PCBs in water, sediments and fish are expected to decline by 10.9 to 17.4% relative to baseline levels in the sections of the River downstream from the City of Spokane facilities as a result of implemented and planned PCB discharge reductions at the City of Spokane facilities.

4. DATA & INFORMATION CONSULTED

In developing my analysis and opinions, I examined the following data and information:

- Available datasets (see **Attachment C**)
- Reports
- Peer-reviewed literature

Attachment B contains a comprehensive list of the data and information consulted, including a list of all documents reviewed.

5. BACKGROUND INFORMATION

5.1. The Spokane River

5.1.1. Geography

The Spokane River (the “River”) originates from Lake Coeur d’Alene in Western Idaho, and flows east to west for 112 RM. The River drains into Franklin D. Roosevelt Lake, a reservoir of the Columbia River created by the Grand Coulee Dam in Eastern Washington State. Of the 112 RM, the majority (i.e. lower 96.1 RM), are contained within Washington State (Serdar et al. 2011, LimnoTech 2016a).

The Spokane River is located in the Columbia Plateau geographic region of Eastern Washington and Northern Idaho. The River initially runs through the Rathdrum Prairie in Idaho, and then zigzags through the southern extend of the Selkirk Mountains. The surrounding terrestrial environment is predominately permeable glacial till and outwash soil overlaying bedrock. These geographic characteristics, combined with limited precipitation in this semi-arid region, result in minimal surface runoff to the River (Beckwith 2003).

A number of municipalities dot the Spokane River including Post Falls ID, Coeur d’Alene ID, Liberty Lake WA, Deer Park WA, and Medical Lake WA, and the larger urban areas encompassing the City of Spokane and Spokane County in Eastern Washington. The cities of Wallace ID and Kellogg ID, among others, are upstream from Lake Coeur d’Alene. The downstream extent of the Spokane River (RM 32.5 to RM 0) forms the southern boundary of the Spokane Tribe of Indians Reservation (Serdar et al. 2011, LimnoTech 2016a).

There are two main tributaries to the Spokane River: Latah Creek (formerly Hangman), and Little Spokane River. Coulee Creek converges with Deep Creek just before entering the Spokane River. Deep Creek is a minor tributary that is often dry in lower reaches (Johnson and Norton 2001, Serdar et al. 2011, Wong and Era-Miller 2019c).

The Spokane River has seven hydroelectric dams that operate under natural flow regimes. The dams create a series of pools, with the largest being the 24-mile long Lake Spokane reservoir (Serdar et al. 2011, Mathieu 2018). The dams and other geographic markers of the Spokane River are shown in **Table 1** and **Figure 1** based on (Serdar et al. 2011, LimnoTech 2016a).

Table 1: River miles of geographic markers in the Spokane River.

River Mile	Geographic Marker
112	Lake Coeur d'Alene Outlet
102	Post Falls Dam
96.1	Idaho-Washington Stateline
85.3	Trent Avenue Bridge
83.25-83.75	Donkey Island sediment depositional area above Upriver Dam
80.2	Upriver Dam
77.0	Greene Street Gauge
74.7	Upper Falls Dam (coupled with second dam structure at Monroe Street)
74.0	Monroe Street Dam
72.9	Spokane Gauge
72.2	Entry of Latah (Hangman) Creek into the Spokane River
59.0	Entry of Coulee/Deep Creek into Spokane River (Avista Corporation 2006)
58.1	Nine Mile Dam
56.3	Entry of Little Spokane River into Spokane River
33.9	Long Lake Dam, which creates Lake Spokane (formerly Long Lake)
29.3	Little Falls Dam
0	Franklin D. Roosevelt Lake

5.1.2. Hydrology

The Spokane River watershed encompasses approximately 6,600 square miles (17,100 km²), with more than half of this area located in Idaho (3,800 square miles or 9,842 km²) and the remainder in Washington. Lake Coeur d'Alene has two primary inflows: Coeur d'Alene River and St. Joe River, whose headwaters are in subranges of the Bitterroot Mountains west of the Idaho-Montana border (Jack et al. 2003, Parsons and Terragraphics Inc. 2007, Serdar et al. 2011).

The Spokane Valley-Rathdrum Prairie Aquifer (the "Aquifer") underlies the Spokane River from Lake Coeur d'Alene outlet to approximately Nine Mile Dam (MacInnis 2009). The Aquifer interacts with the Spokane River; both receiving and contributing in excess of one billion gallons per day in bidirectional flow (Hobbs et al. 2019). The Spokane River typically loses flow from the outlet of Lake Coeur d'Alene to downstream of the Stateline (about RM 90.4 at Barker Road) as it recharges the Aquifer. Between Stateline/Barker Road and the City of Spokane (Spokane Gauge at RM 72.9), flow rates gradually increase due to groundwater inputs (Serdar et al. 2011, LimnoTech 2016a).

The two main tributaries provide influx of water to the Spokane River. Latah Creek is smaller and extremely flashy, responding rapidly to rainfall and snowmelt with an average flow range of 20 to 20,000 cubic feet per second (cfs; or 0.57-570 m³/s) (Washington State Department of Ecology 1994). The discharge volume from Little Spokane River is 10-times higher than that of Latah Creek (Serdar et al. 2011). Deep Creek and Coulee Creek contribute minimally to the Spokane River. Deep Creek is often dry in the lower reaches (Wong and Era-Miller 2019c).

Seasonal flow regimes in the Spokane River are driven by precipitation, freezing temperatures in the winter and the onset of snowmelt in the spring ("freshet"). Flow rates are also partially controlled by Post Falls Dam for approximately half of the year (Jack et al. 2003, Serdar et al. 2011, LimnoTech 2016a). Long Lake Dam controls the level of Lake Spokane, the largest reservoir in the Spokane River.

A hydrograph of average flows at the Spokane Gauge (RM 72.9) in 2018 (**Figure 2**), shows the seasonal flow regime of the River. Maximum flow rates (27,700 cfs or 784 m³/sec) occurred in late spring due to freshet and minimum flows (1,020 cfs or 29 m³/sec) occurred in late summer.

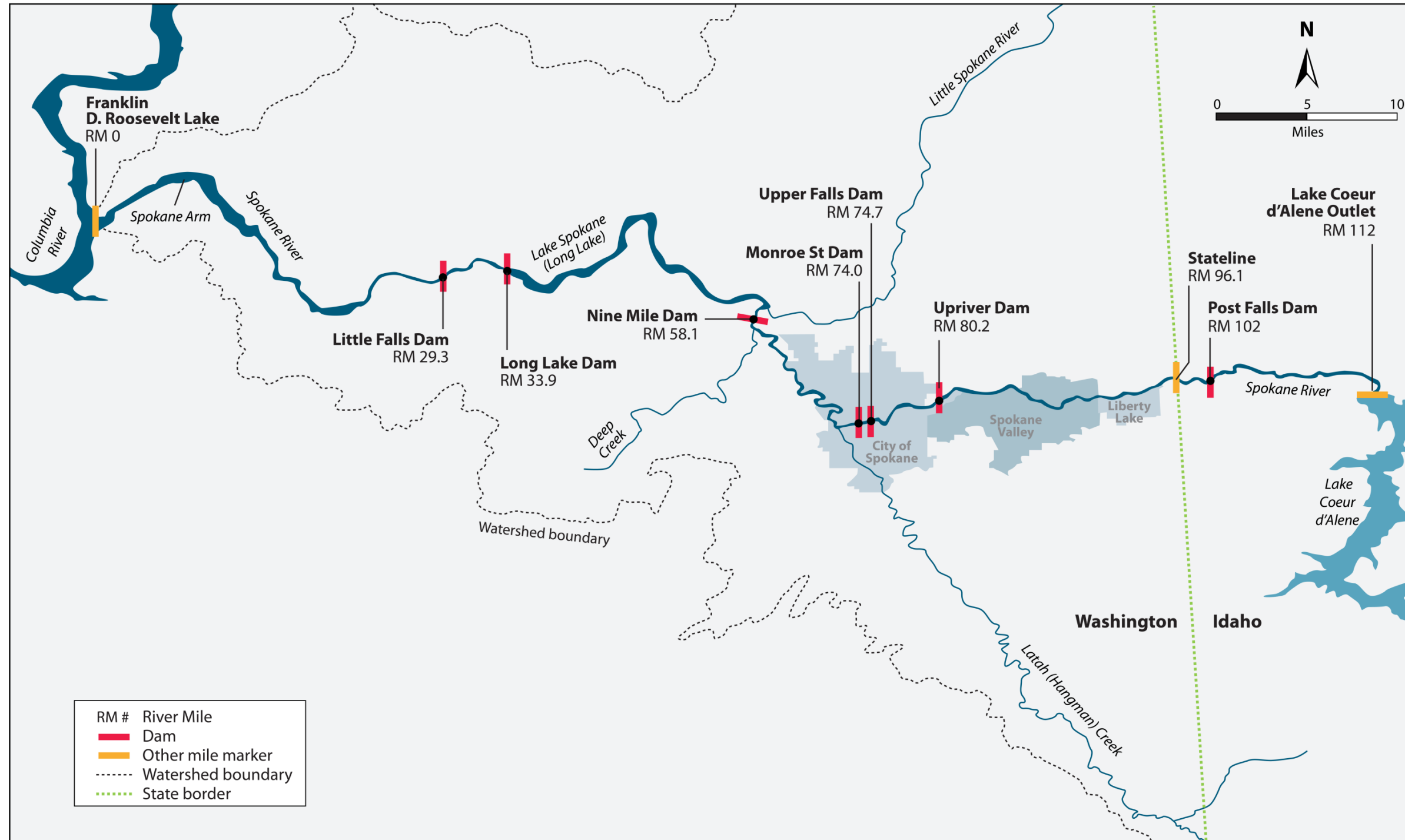


Figure 1: Map of the Spokane River showing dams and river mile markers.

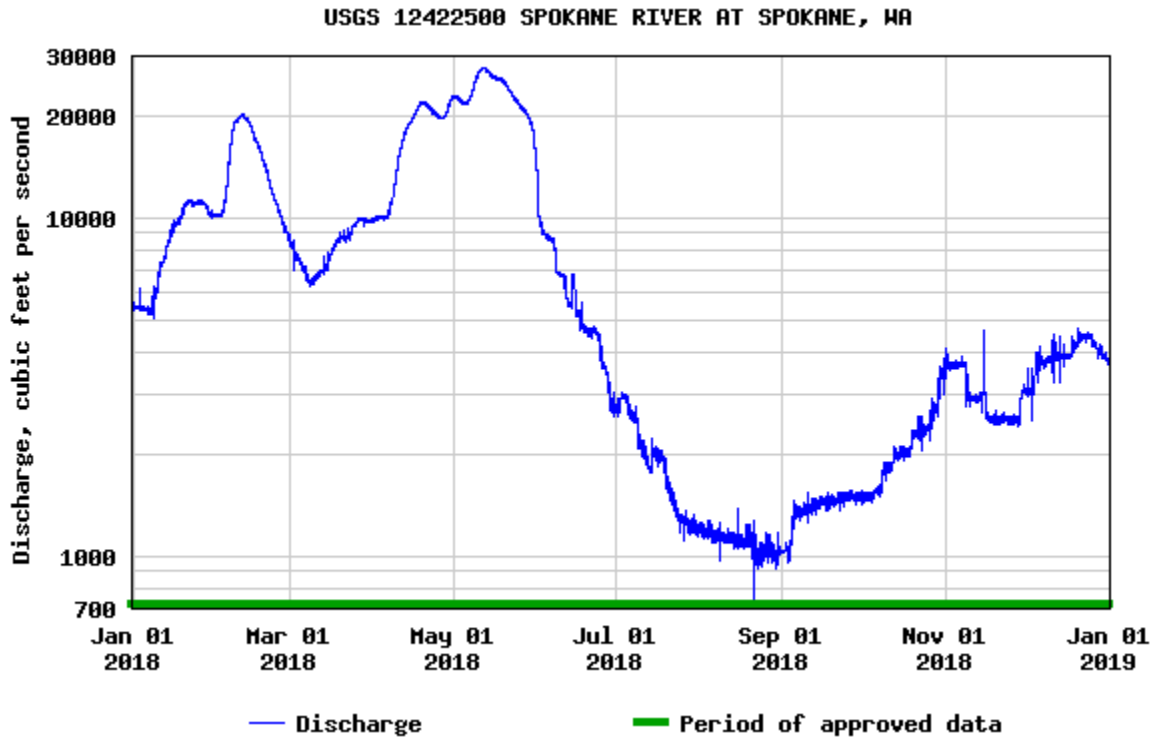


Figure 2: Spokane River hydrograph of average daily discharge (cubic feet per second) at Spokane, WA USGS 12422500 gauge (RM 72.9) for the period of January 2018 to January 2019. Developed using data accessed from the USGS National Water Information System (United States Geological Survey 2019)

Stream flows, measured approximately every 15 minutes by a stream gauge, are shown from upstream to downstream in the River in **Figure 3** (2018) and **Figure 4** (2005). The 2018 annual mean flow slightly increases from 7,035 cfs at Post Falls (RM 102) to 7,546 cfs at Spokane gauge (RM 72.9), reflecting the influence of groundwater influx over this reach. This pattern was also observed in 1969-2016 data, reported by (LimnoTech 2016a). Flow increases further to 8,588 cfs at Long Lake (2018), due to groundwater and tributary influx. While fewer monitoring locations were available for 2005, upstream to downstream patterns in flow rates were similar to those measured in 2018.

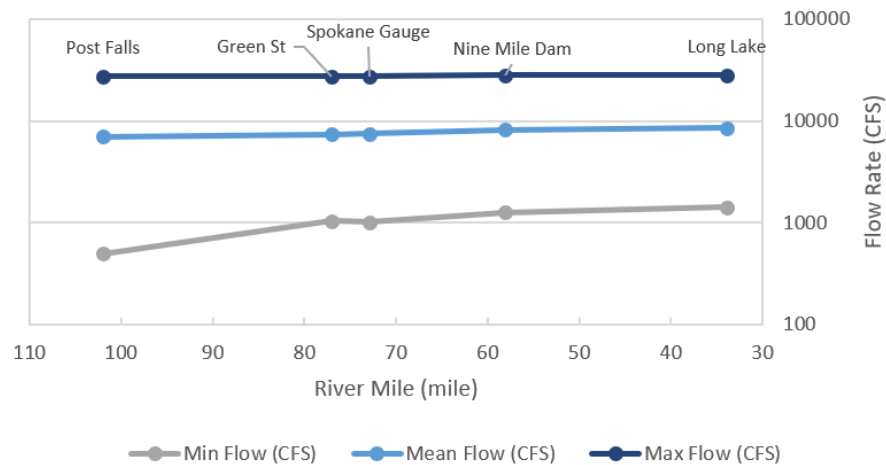


Figure 3: Spokane River 2018 flow rates (annual mean, minimum, and maximum; cubic feet per second) as a function of river mile from upstream to downstream at Post Falls (RM 102), Greene Street (RM 77.0), Spokane Gauge (RM 72.9), Nine Mile Dam (RM 58.1) and Long Lake Dam (RM 33.9). Developed using data accessed from the USGS National Water Information System (United States Geological Survey 2019).

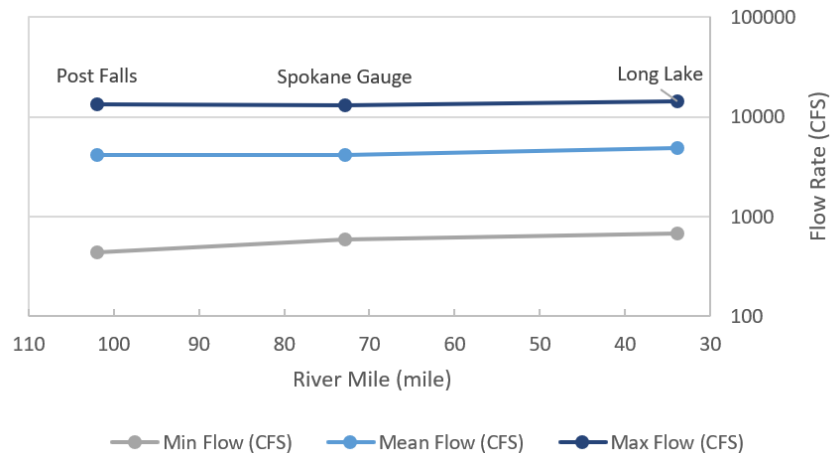


Figure 4: Spokane River 2005 flow rates (annual mean, minimum, and maximum; cubic feet per second) as a function of river mile from upstream to downstream at Post Falls (RM 102), Spokane Gauge (RM 72.9) and Long Lake Dam (RM 33.9). Developed using data accessed from the USGS National Water Information System (United States Geological Survey 2019).

5.1.3. Sediments

A defining feature of the Spokane River is the general absence of fine depositional sediments, with much of the riverbed consisting of gravel, cobbles and boulders (Serdar et al. 2011, Wong and Era-Miller 2019c). High river velocities in the Spokane River scour the riverbed, even behind the dams. An exception to this is an area of sediment deposition behind Upriver Dam/Donkey Island, which was remediated (capped) in 2007 for PCB contamination (Serdar et al. 2011). Lake Spokane is another exception. Water in this large reservoir moves at low velocities, resulting in the highest sediment deposition in the River (Mathieu 2018).

The Spokane River receives little sediment load between Lake Coeur d'Alene, which acts as a sediment settling basin, and Latah Creek, the first tributary to enter at RM 72.2. Latah Creek and the Little Spokane River both contribute sediments to the Spokane River above Lake Spokane. Latah Creek is prone to erosion and provides slightly higher sediment loads than the larger Little Spokane River (Johnson and Norton 2001, Serdar et al. 2011).

5.1.4. Fish and Aquatic Resources

The Spokane River is home to a diverse Pacific Northwest freshwater ecosystem. A variety of species of flora and fauna ranging in complexity from bacteria and aquatic algae (e.g. periphyton) to invertebrates and fish inhabit this River. The organisms that make up an aquatic ecosystem can be categorized based on their trophic position or level in the food web. Aquatic ecosystems generally contain four trophic levels. Primary producers such as phytoplankton, algae, and periphyton comprise the lowest trophic level. The second trophic level includes primary consumers such as invertebrates living in the water column (pelagic) or associated with sediments (benthic). Invertebrates feed upon primary producers and organic detritus. Foraging fish make up the third trophic level which are in turn fed upon by predatory fish which make up the fourth trophic level (ISAB 2011).

i Periphyton & Aquatic Plants

Periphyton (or biofilm) refers to a mixture of algae, bacteria, microbes, and detritus that attaches to and grows on rocks or other submerged surfaces in aquatic ecosystems. This material can serve as the base of the food web and supplies nutrients to invertebrates (Wong and Era-Miller 2019c). Periphyton can be found throughout the Spokane River and has been recently sampled for measuring PCB concentrations at the base of the food web (Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c).

Aquatic plants (macrophytes) are another group of primary producers that can provide important food and shelter to invertebrates and fish. These plants tend to occur in shallower areas with slower moving water. Large aquatic macrophyte beds are present in Lake Spokane, starting about 2.5 miles below Nine Mile Dam. These beds cover approximately 15 miles of river length along the northern shoreline of Lake Spokane, which is characterized by gentle slopes and shallow bays (Osborne et al. 2003).

ii Invertebrates

Pelagic invertebrates are small organisms that live suspended in the water column. Some examples of “micro-zooplankton” include calanoid copepods, pelagic cladocerans, and rotifers. These primary consumers rely on the flow of water for their movement and ability to collect food (Plotnikoff 1997).

Freshwater benthic invertebrates are organisms that reside on or within sediments or bottom substrates of freshwater lakes, rivers, and streams. These animals may spend part or all of their lives in the aquatic system, with some only found in freshwater during their larval stage and emerge to become terrestrial insects as adults. Benthic invertebrates are low in the food web, mainly feeding upon leaf litter, substrate algae, organic matter, or suspended solids and algae. Examples of groups of benthic invertebrates that are often monitored in riverine and stream systems include mayflies, caddisflies, plecoptera, and diptera (Plotnikoff 1997).

Crayfish are larger invertebrate crustaceans related to lobsters that live in freshwater systems, including the Spokane River. *Pacifastacus leniusculus*, a brightly-colored species native to the Pacific Northwest, are resident to the Spokane River and feed opportunistically on a variety of diet items (U.S. Fish and Wildlife Service 2011).

iii Fish

Fish represent higher trophic levels in the food web, including both foragers and predators. The Spokane River, and the reservoirs and pools located along it, contain a variety of habitats suitable for cold, cool, and warmwater species. Fish species are specialized to take advantage of these niches based on their tolerance of and preference for certain water characteristics such as water temperature, flow rate, and depth.

Lee and King (2013) investigated the assemblage of fish species present in the middle Spokane River, between Upriver Dam (RM 80.2) and Upper Falls Dam (RM 74.7), and found minnows, suckers, trout, sculpin, bass, sunfish and perch. The most abundant fish species was the Redband Trout (*Onchorynchus mykiss gairdneri*), the Spokane River’s native

subspecies of the Rainbow Trout, closely followed by the Largescale Sucker (*Catostomus macrocheilus*). Other species observed included Mountain Whitefish (*Prosopium williamsoni*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Redside Shiner (*Richardsonius balteatus*), and Smallmouth Bass (*Micropterus dolomieu*). Hatchery origin Rainbow Trout have been stocked into the middle Spokane River.

Osborne et al. (2003) surveyed both inshore and offshore habitats of Lake Spokane (RM 58.1-33.9) and found Northern Pikeminnow, Yellow Perch (*Perca flavescens*), and Largescale Sucker were the most abundant species. Fish species assemblages differed between habitats of the Lake. Lake Spokane is managed by the Washington State Department of Fish and Wildlife as a mixed species fishery and has been stocked with Rainbow Trout, Brown Trout (*Salmo trutta*), Eastern Brook Trout (*Salvelinus fontinalis*) and Smallmouth Bass. Popular gamefish include Mountain Whitefish, Redband/Rainbow Trout, Yellow Perch, and bass. **Table 2** lists several of the fish and crayfish species present in the Spokane River.

Table 2: Fish and crayfish present in the Spokane River system including common names, scientific name, taxon group, and invasive status.

Common Name	Scientific Name	Taxon Group	Native/ Invasive
Black Crappie	<i>Pomoxis nigromaculatus</i>	Sunfish	Invasive
Bridgelip Sucker	<i>Catostomus columbianus</i>	Sucker	Native
Brown Trout	<i>Salmo trutta</i>	Salmonid	Invasive
Channel Catfish	<i>Ictalurus punctatus</i>	Ray-finned fish	Invasive
Chiselmouth	<i>Acrocheilus alutaceus</i>	Minnow	Native
Common Carp	<i>Cyprinus carpio</i>	Carp	Invasive
Crayfish (Signal Crayfish)	<i>Pacifastacus leniusculus</i>	Crayfish	Native
Kokanee Salmon	<i>Oncorhynchus nerka</i>	Salmonid	Native
Largemouth Bass	<i>Micropterus salmoides</i>	Bass	Invasive
Largescale Sucker	<i>Catostomus macrocheilus</i>	Sucker	Invasive
Longnose Sucker	<i>Catostomus catostomus</i>	Sucker	Invasive
Mountain Whitefish	<i>Prosopium williamsoni</i>	Salmonid	Native
Northern Pikeminnow	<i>Ptychocheilus oregonensis</i>	Minnow	Native
Rainbow Trout (hatchery)	<i>Oncorhynchus mykiss</i>	Salmonid	Hatchery
Redband Trout	<i>Oncorhynchus mykiss gairdneri</i>	Salmonid	Native
Redside Shiner	<i>Richardsonius balteatus</i>	Minnow	Native
Sculpin spp. (e.g. Columbia sculpin)	<i>Cottus spp.</i> (<i>Cottus hubbsi</i>)	Sculpins	Native
Smallmouth Bass	<i>Micropterus dolomieu</i>	Bass	Invasive
Tench	<i>Tinca tinca</i>	Cyprinid	Invasive
Walleye	<i>Sander vitreus</i>	Perciform	Invasive
Westslope Cutthroat Trout	<i>Oncorhynchus clarki lewisi</i>	Salmonid	Native
White Crappie	<i>Pomoxis annularis</i>	Ray-finned fish	Invasive
Yellow Perch	<i>Perca flavescens</i>	Perches	Invasive
Pumpkinseed Sunfish	<i>Lepomis gibbosus</i>	Sunfish	Invasive
Brown Bullhead	<i>Ameiurus nebulosus</i>	Catfish	Invasive
Yellow Bullhead	<i>Ameiurus natalis</i>	Catfish	Invasive

A brief description of some of the key fish species in the Spokane River, and their dietary preferences, is provided below for native fish species:

- The Redband Trout/Rainbow Trout is a cold-water salmonid that is important to sport fishing as well as the integrity of the Spokane River freshwater ecosystem. Redband is the native subspecies and other Rainbow Trout are released from hatcheries. The natural range of Rainbow Trout includes freshwater tributaries to the Pacific Ocean. These 1-5 lb (0.5-2.3 kg) fish inhabit highly-oxygenated low-temperature shallow lotic (fast flowing) systems featuring gravel substrates. While opportunistic, this predatory species mostly feeds upon benthic invertebrates such as caddisflies, stoneflies, mayflies, and dipterans (British Columbia Ministry of Fisheries 2018, Wong and Era-Miller 2019c).
- Mountain Whitefish is a salmonid mountain-dwelling species with a range throughout the Western reaches of North America (Starnes 2019). Its prey includes crayfish, snails, and amphipods (Moyle 2002). Mountain Whitefish prefer aquatic environments featuring deep, cold-water pools with a tendency to reside in the lower portion of the water column (Moyle 2002).
- Largescale Sucker is a fish species that feeds upon benthic invertebrates, algae, and plant material opportunistically on the creek bottom. The species is distributed throughout the Columbia River system including the Spokane River and its tributaries (Williams et al. 2014). Largescale Sucker are an important source of food to both piscivorous fish and stream-feeding mammals (Williams et al. 2014).
- The Bridgelip Sucker (*Catostomus columbianus*) is a native species to the Columbia River system that inhabits the margins of lakes, river pools, and riffles. The main sources of food are algae and benthic invertebrates (Eigenmann 1893).
- The Northern Pikeminnow is a native Pacific Northwest warm-water fish that prefers slower flow rates. It benefits from the construction of dams due to the reduced stream velocity created upstream of the structures. Pikeminnow feed on a variety of benthic invertebrates that inhabit muddy and gravel streambeds (Bradford 2004).

Some of the common invasive fish species present in the Spokane River include:

- Common Carp is a large deep-bodied fish that inhabits the Spokane River. This species is native to Asia but has become widely distributed throughout North America. Carp feed upon aquatic vegetation and prefer warm, shallow bodies of water (DFO 2018).

- The invasive Smallmouth Bass is a cool-water fish tolerant of high-water temperatures prefers streams with alternating pools and riffles. Adults prey upon insects, crayfish, and fish, including minnows, sculpin, and juvenile salmonids (Brown 2009a).
- Brown Trout are native to Europe but have been introduced to North America as game fish (Hart 1973). Similar to other salmonids, Brown Trout feed upon invertebrates and prey fish. This recreationally-important species now features a range in the United States including the Upper Spokane where they are stocked (United States Geological Survey 2019).
- Although native to North America, Largemouth Bass is an invader in the Spokane River. Largemouth Bass are habitat generalists but do best in shallow nearshore zones with extensive aquatic vegetation. This species mainly predares upon juvenile and small-bodied adult fish forage, crayfish, and insects (Brown 2009b).
- Yellow Perch are native to large portions of North America but invasive to the Spokane River. Juveniles feed upon the larval benthic invertebrates as well as zooplankton invertebrates. Adults consume insects, invertebrates, fish eggs, juvenile fish, and crayfish. These cool-water fish are found in low-velocity rivers but are also tolerant of brackish and saline conditions (Brown 2009c).

iv Fish Movement

Both natural and anthropogenic barriers in aquatic systems will influence fish movement and can affect biodiversity and population structure of fish species (Small et al. 2007). Migratory fish originating from the Columbia River have not been found in the Coeur d'Alene sub-basin due to natural barriers in the Spokane River such as the Spokane Falls located at approximately RM 74, as well as other falls at RMs 96, 84, and 64. Fish movement and migration in the Spokane River is further limited by large dams, increasing the impediments already created by natural falls (Northwest Power and Conservation Council 2000, Northwest Power and Conservation Council 2019).

Small et al. (2007) conducted genetic studies on fish of the Spokane River to investigate intermixing of stocks and fish movement. They report that native steelhead (anadromous *O. mykiss gairdneri*) were eliminated from the Spokane River in the 1900s because steelhead were unable to migrate to and from the ocean due to dam construction. They also report that hatchery fish have genetically mixed with native populations in tributaries containing hatcheries and in locations where hatchery fish have escaped. However, native inland Redband Trout have been retained in areas separated from hatcheries by dam barriers. This

demonstrates that dams in the Spokane River disrupt fish movement and connectivity between Rainbow Trout sub-groups.

Movement of Redband Trout was also monitored in 2003 by radio tagging fish in the upper Spokane River (Post Falls Dam at RM 102 to Upriver Dam at RM 80.2) and farther downstream between Monroe Dam (RM 74.0) and Nine Mile Dam (RM 58.1) (Parametrix 2004). During the spawning period, fish tended to move very short distances (often less the 0.5 miles) to available spawning habitat. While movement increased after spawning, sometimes in response to seeking refuge from increased water temperatures, fish generally stayed within several miles of the location from where they were released. Out of 55 fish tagged in the upper reach during two events, only two fish migrated to the lower study area, passing three dam structures. This study, as well as others such as Osborne et al. (2003), indicate that, while the occasional fish may migrate across dam structures of the Spokane River, in general, fish remain within river reaches between dams of the Spokane River.

v Uses of Aquatic Resources & Consumption Restrictions

The Spokane River is an important source of economic and recreational value. Hydroelectric power generation, agricultural irrigation, industrial use, and cultural activities rely on the River (Wong and Era-Miller 2019c). In addition, the Spokane River is used for recreational and sport fishing. Lake Spokane is the largest hydroelectric reservoir along the Spokane River and is a managed fishery (Osborne et al. 2003). The Spokane River is regularly stocked with sport fish.

Fish consumption advisories³, related to PCB contamination, are in effect for the Spokane River and apply to various species and reaches defined by WDOH (2019) as shown in **Table 3**.

³ In addition to these fish consumption advisories related to PCBs, two statewide fish consumption advisories are in place and apply to every waterbody in Washington State. Both advisories are for mercury contamination, and are intended for pregnant or nursing women and children. These include a Do Not Eat advisory for Northern pikeminnow and a limit of 2 meals per month for Largemouth Bass and Smallmouth Bass.

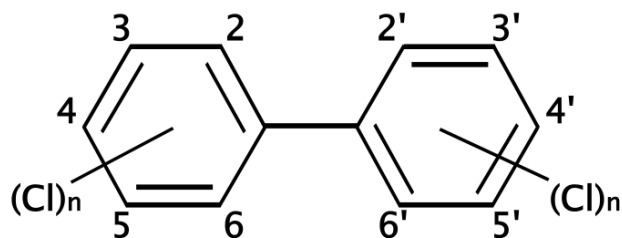
Table 3: Washington State Department of Health fish consumption advisories for the Spokane River.

Fish Species	Idaho Border to Upriver Dam (RM 96.1-80.2)	Upriver Dam to Nine Mile Dam (RM 80.2-58.1)	Long Lake (Lake Spokane) (RM 58.1-33.9)	Little Falls Pool (RM 33.9-29.3)	Spokane Arm (RM 29.3-0)
All Species	Do Not Eat	-	-	-	-
Brown Trout	-	-	1 meal/month	-	4 meals/month
Common Carp	-	-	Do Not Eat	-	-
Largescale Sucker	-	2 meals/month	1 meal/month	4 meals/month	1 meal/month
Mountain Whitefish	-	1 meal/month	2 meals/month	-	-
Northern Pikeminnow	-	-	2 meals/month	4 meals/month	-
Rainbow Trout	-	2 meals/month	4 meals/month	-	4 meals/month
Yellow Perch	-	-	8 meals/month	-	-

5.2. PCBs

5.2.1. What are PCBs?

PCBs are a group of persistent hydrophobic organic chemicals. PCBs consist of two joined benzene (phenyl) rings on which one or more chlorines have been substituted for the hydrogens (**Figure 5**).

**Figure 5: Chemical structure of PCBs.**

Because the chlorine atoms can be in various positions on the two rings, there are a total of 209 possible PCB molecules, which are referred to as congeners. The numbering system for the positions of the chlorines is shown in **Figure 5**. 2, 2', 6, and 6' are called ortho positions; positions 3, 3', 5, and 5' are called meta positions; and positions 4 and 4' are called para positions (ATSDR 2000). The International Union of Pure and Applied Chemistry has developed an identification system in which higher numbered congeners have more chlorines (i.e. PCB 1 has one chlorine (2-chlorobiphenyl) and PCB 209 has ten chlorines (2,2',3,3',4,4',5,5',6,6'-decachlorobiphenyl)). A group of congeners having the same number of chlorines is called a homologue (sometimes spelled homolog).

There are no natural sources of PCBs. The sole manufacturer of PCBs in the United States was the Monsanto Company, which sold PCBs using the tradename "Aroclor" (Sofaer 1976). Not all Aroclors consisted solely of PCBs, but Aroclors 1016, 1242, 1248, 1254, and 1260 consisted almost entirely of PCBs and together constituted about 97 percent of all Aroclors produced (Brown 1994). Monsanto's numbering scheme used the last two digits of the Aroclor designation to refer to the chlorine content of the mixture (i.e. Aroclor 1242 was 42 percent chlorine by weight). The exception to this numbering scheme is Aroclor 1016. Monsanto began producing Aroclor 1016 in 1974 as a derivative of Aroclor 1242 (ATSDR 2000). These two Aroclors therefore have similar congener patterns except that Aroclor 1242 contained six to seven percent of homologues with five or more chlorines and Aroclor 1016 contained about 0.4 percent of such homologues (Erickson 1997).

PCBs were banned from production in the United States in 1977 because they are toxic, persistent, and bioaccumulative. The properties of PCBs work in concert to make PCBs particularly problematic in the environment. The United Nations has classified PCBs as a Persistent Organic Pollutant or POP because of its properties and its risk to global environmental and human health under the UN Stockholm Convention.

5.2.2. Physical and Chemical Properties of PCBs

Most PCB congeners do not readily degrade under most environmentally relevant conditions. The 209 PCB congeners have physical-chemical properties that vary widely, primarily as a function of the number of chlorines. These physical-chemical properties determine the role that volatilization, dissolution, and transport have in controlling the ultimate fate of the PCBs in the Spokane River. The properties of PCBs that are most important in determining the environmental fate of PCBs are aqueous solubility, Henry's law

constant, and hydrophobicity as expressed by the octanol-water partition coefficient (K_{ow}).

Table 4 provides numeric values for these and other properties.

Table 4: Physical and chemical properties of some Aroclors. Adapted from (ATSDR 2000).

Property	Aroclor 1016	Aroclor 1221	Aroclor 1242	Aroclor 1254	Aroclor 1260
Molecular weight (g/mol)	257.9	200.7	266.5	328	357.7
Color	Clear	Clear	Clear	Light yellow	Light yellow
Physical state	Oil	Oil	Oil	Viscous liquid	Sticky resin
Density (g/cm ³ at 25°C)	1.37	1.18	1.38	1.54	1.62
Aqueous solubility (mg/L at 25°C)	0.42	0.59	0.24, 0.34, 0.10	0.012, 0.057	0.0027, 0.08
Log Kow	5.6	4.7	5.6	6.5	6.8
Vapor pressure (mm mercury at 25°C)	0.0004	0.0067	0.000406	0.0000771	0.0000405
Henry's law constant (atm-m ³ /mol at 25°C)	0.00029	0.0035	0.00052	0.002	0.0046

The aqueous solubility of PCBs varies over several orders of magnitude, with congeners containing more chlorines generally having a lower aqueous solubility. Because Aroclors 1016, 1221, and 1242 contain mostly congeners with three or four chlorines, they are generally more soluble than Aroclors 1254 and 1260, which contain congeners with more chlorines (ATSDR 2000).

The Henry's law constant is the equilibrium partition coefficient between water and air. It is important in controlling the rate and extent of volatilization of the PCBs from the dissolved phase in the water column to the air. The Henry's law constants of some Aroclors are high enough that PCBs dissolved in water can volatilize into the atmosphere (NUS Corporation 1984).

The hydrophobicity of PCBs causes them to sorb to relatively non-polar media, such as lipids and natural organic matter, rather than remain dissolved in water. Hydrophobicity is usually expressed as the octanol-water partition coefficient (K_{ow}). Octanol resembles lipids in organisms in many ways. Hence, octanol is a good surrogate phase for lipids and K_{ow} values of PCBs are approximately equal to the partition coefficients of PCBs between water and lipids of organisms. Log K_{ow} values for the most common Aroclors are in the range of 5.6 to 6.8, meaning that the PCBs in these Aroclors are $10^{5.6}$ to $10^{6.8}$ (about 400,000 to 6.3 million) times more likely to dissolve into octanol than into water, when exposed to both. Hence, PCBs have a very high affinity for lipids of aquatic biota and tend to accumulate in the lipids of fish. The high hydrophobicity of PCBs causes PCBs to sorb onto natural organic matter in sediment, where they can remain for long periods of time, as the reverse process of desorption is generally very slow.

5.2.3. Measuring PCBs

Measuring the concentration or amount of PCBs in the environment is complex because PCBs consist of 209 closely related compounds. The most frequently used methods for measuring PCBs report “sum of PCBs” or “total PCBs” even though they do not always measure or report all 209 congeners. Sum of PCBs or total PCBs typically refers to the sum of the concentrations of those PCB congeners that have been included in the analysis. The number of PCB congeners included in the analysis can vary among studies. However, in general, most analytical laboratories attempt to include all the PCB congeners that contribute significantly to the total concentration of PCBs.

There are different analytical methods for measuring the concentrations of PCBs in a matrix. These include “low resolution” analysis that tests for an Aroclor mixture, a “high resolution” method that quantifies concentrations of individual PCB congeners and an in-between technique that measures PCB homologue groups (Louis Berger US 2019). The Aroclor method involves the analytical chemist identifying distinct patterns in the gas chromatograph that are characteristic of one of the commercial Aroclor mixtures. For example, while an Aroclor mixture may include >100 PCB congeners, a relatively smaller number of these congeners (e.g. 10-20) may comprise more than half of the mixture. These congener proportions provide the Aroclor signature. One disadvantage of the Aroclor method is that, once released in the environment, PCBs are subject to a number of fate processes (degradation, weathering, dechlorination, transport, uptake into organisms, etc.) that act to change the congener composition in an environmental sample from the original source Aroclor mixture. Due to uncertainty in the methodology, Aroclor quantitations can over- or under-report PCB concentrations. The high-resolution congener method is considered the most accurate

quantification of PCB congeners and total PCBs in environmental samples. However, this method requires more sophisticated analysis and is therefore more costly (Louis Berger US 2019).

PCB concentration data used in this report includes total PCB concentrations determined using both Aroclor and congener-based methods. In this report, the terms “sum of PCBs” and “total PCBs” refer to adding together all the concentrations of all the congeners, or Aroclors, that were included in the analysis⁴.

5.3. PCB Studies in the Spokane River

Numerous studies have investigated PCB concentrations in fish/crayfish tissues, sediment and water of the Spokane River. These studies date back to the late 1970’s (Joy 1984, Hopkins et al. 1985, Hopkins 1991), with early investigations by Washington’s State Department of Ecology and USEPA targeting fish collections. Ecology continued monitoring PCBs in Spokane River fish throughout the 1990s (Davis 1994, Davis and Serdar 1994, Serdar et al. 1994, Johnson 1994a, Johnson 1994b, Davis et al. 1995, Ecology 1995, Johnson 1997, Johnson 2000) and 2000s (Jack and Roose 2002, Seiders and Kinney 2004, Seiders et al. 2006, Serdar and Johnson 2006, Seiders et al. 2007, Serdar et al. 2011, Seiders et al. 2014). Studies identified elevated PCB concentrations in fish from the Spokane River, relative to other waterbodies in Washington State (COS and RPWRF 2017) and relative to State and Federal screening criteria (Serdar et al. 2011, Ecology 2017). PCB concentrations in fish reportedly have declined in the Spokane River over time (Serdar and Johnson 2006, Serdar et al. 2011, Seiders et al. 2014). Fish data have been used in an ecological risk assessment (Johnson 2001) and human health consumption advisories, which are currently in-effect (see [Table 3](#)) (WDOH and SRHD 2009, WDOH 2011, WDOH 2019).

The most comprehensive recent studies on PCB concentrations in fish from the Spokane River are from 2003 and 2004 (Serdar et al. 2011), 2005 (Serdar and Johnson 2006), and 2012 (Seiders et al. 2014). More recent biota collections have targeted specific fish species such as Common Carp, (Era-Miller 2015a), and 1-year old hatchery-raised Rainbow Trout, (Wong 2018), or lower trophic level organisms, such as periphyton/biofilm and invertebrates (Wong and Era-Miller 2019b, Wong and Era-Miller 2019c).

⁴ Note that in rare cases, only a very limited number of congeners, of the possible 209 congeners, were quantified in the analysis of fish tissue or sediment. These data were not included in the total PCB data set; see [Attachment C](#) for details.

The Spokane River is generally described as erosional with few depositional areas (Serdar et al. 2011). As a result, there are few studies on PCB concentrations in bottom sediments. However, depositional areas near Upriver Dam (RM 80.2), Monroe Street below Upper Falls Dam (RM 74.7) and throughout Lake Spokane (RM 58.1-33.9) have been investigated between 1990 and 2018 through a combination of surface grab and core sampling (Hopkins 1991, Serdar et al. 1994, Batts and Johnson 1995, Ecology 1995, Johnson and Norton 2001, Anchor Environmental LLC 2005, Serdar et al. 2011, Fernandez 2012, Ecology 2015, Borgias and Hamlin 2017, Mathieu 2018, Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c). Coring data on PCB concentrations in Lake Spokane sediments indicate declining PCB concentrations from peak levels in the 1960s. However, these results show relatively consistent concentrations of PCBs in Lake Spokane sediments from approximately 1990 to 2016 (Serdar et al. 2011, Mathieu 2018).

Measuring PCB concentrations in surface water is challenging due to PCB's low solubility in water, resulting in low concentrations, which can be difficult to detect. As a result, methods that involve continuous flow sampling over long time periods and/or extraction of PCBs onto solid phases (e.g. continuous low level aqueous monitoring [CLAM] devices; semipermeable membrane devices [SPMDs]; solid phase extraction disks [SPE]) have been used to measure PCBs in Spokane River surface water (Ecology 1995, Anchor Environmental LLC 2005, Ecology 2005, Sandvik 2009, Sandvik 2010, Sandvik and Seiders 2011, Serdar et al. 2011, Sandvik and Seiders 2012, Era-Miller 2014a, Era-Miller and McCall 2017). PCB concentrations in water determined from SPMD, SPE and CLAM methods were considered by the investigators to be unreliable and data have not been entered into Washington's Environmental Information Management System (EIM) database. The main issue with SPMD, SPE and CLAM water data, as cited by the study investigators, is high levels of background contamination of PCBs introduced during the sampling and analytical process, including from the filters/membranes and filter-housings (Sandvik and Seiders 2012, Era-Miller 2014a, Era-Miller and McCall 2017). Background contamination is tested for by measuring PCB concentrations in method blank samples. Blank samples are composed of a PCB analyte-free matrix that is analyzed in the same manner as a field-collected environmental sample, using the same sample preparation and laboratory techniques (LimnoTech 2014).

Grab samples of Spokane River surface water have been collected by Ecology (Golding 2001, Serdar et al. 2011, Era-Miller 2014a, Era-Miller and McCall 2017, Hobbs et al. 2019) and most recently during several investigations of PCB sources to the River undertaken by LimnoTech on behalf of the Spokane River Regional Toxics Task Force (SRRTTF) (LimnoTech 2015, LimnoTech 2016b, Dilks and Helfand 2017, LimnoTech 2017, LimnoTech 2019). While PCB measurements in water collected through grab sampling are still challenging due to low

environmental concentrations, grab sample measurements have fewer issues with background contamination. LimnoTech (2014) has used a consistent data censoring approach that screens concentrations of each PCB congener in field samples against 3x the concentration of each PCB congener in a blank sample. Congeners present in field samples at concentrations above 3x those in the blank sample are considered "detects". Congeners not-detected by the analysis or detected at concentrations less than 3x the concentration in the blank sample are considered "non-detects".

Recent sampling of the water column has included collection of suspended sediments for PCB analysis using sediment traps (Era-Miller 2014a, Era-Miller and McCall 2017).

Over the 2003-2007 period, a PCB source assessment study⁵ (Serdar et al. (2011) with inputs from Parsons and Terragraphics Inc. (2007)), investigated the reductions in PCB loads required to meet the Human Health Criteria for water quality in-effect at the time (i.e. 170 pg/L for the State of Washington and 3.37 pg/L for the Spokane Tribe of Indians). This study concluded that large reductions in PCB loadings in the River would be needed to meet the Spokane Tribe's criteria. This included a 95% reduction of PCB loading from upstream at the Idaho border, a 97% reduction in the Little Spokane River, and >99% reductions in municipal, industrial, and stormwater discharges. Serdar et al. (2011) reported the largest source of PCBs (totaling 44%) to the Spokane River was the City of Spokane's stormwater and CSO inputs. Upstream PCB river loads, originating from Lake Coeur d'Alene, reportedly comprised 30% of the loads present at Long Lake dam. A food web bioaccumulation model indicated that reductions in concentrations of PCBs in water and sediments of >99% are required to meet the Spokane Tribe's fish tissue criterion in the Spokane Arm. In response to these results, SRRTTF was formed with the goal of making progress in reducing PCBs in the Spokane River system (Ecology 2012, COS and RPWRF 2017).

Remediation works to address PCBs in the Spokane River system to-date have included remediation of contaminated sediments near Upriver Dam and Donkey Island (Anchor Environmental LLC 2005, Ecology 2012, Ecology 2015, LimnoTech 2016a, COS and RPWRF 2017), as well as other efforts to address upland sources (i.e. soil removal in 2009 from a City of Spokane parcel of a former transformer recycling facility; soil removal in 2007 from Kaiser Aluminum; and removal and vitrification of soils in the mid-1990s at a General Electric transformer service site) (Ecology 2012, COS and RPWRF 2017). Other initiatives are

⁵ Formerly referred to as a total maximum daily load [TMDL] study.

underway to remediate PCBs in groundwater from the Kaiser Aluminum facility (Ecology 2010, Leber 2019).

5.4. Sources of PCBs to the Spokane River

On behalf of the SRRTTF, LimnoTech (2016a) prepared a *Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River*, and a memorandum on *Sources and Pathways of PCBs to the Spokane River Watershed* (Dilks 2016a), in which sources of PCBs to the Spokane River system are documented. The dominant source of PCBs in the Spokane River are legacy PCBs produced by Monsanto as Aroclors (LimnoTech 2016a). PCBs enter the Spokane River through point and non-point source inputs. Tributaries, groundwater seepage, combined sewer outfalls, wastewater treatment plants are examples of sources of PCBs. In-river cycling between sediment and water also influences PCB loading. Atmospheric deposition to the watershed is also a suspected source of PCBs. There is limited information on atmospheric deposition rates of PCBs into the Spokane River basin (LimnoTech 2016a).

5.4.1. Legacy PCB Source Areas

5.4.1.1 Contaminated Soils & Groundwater

Soils can have the potential for a high burden of PCBs because of activities like on-land PCB-usage, PCB-leaching from buildings, equipment, and landfills. The high affinity of PCBs to organic content combined with their slow rate of degradation, means that surface soils may remain contaminated for extended periods of time. Loading of PCBs to the Spokane River requires mobilization by way of surface water runoff (e.g. delivered via stormwater discharges) or groundwater leaching. Given that the Spokane River is largely fed by groundwater with minimal surface water tributary inputs, subsurface inputs from solid waste disposal sites is a potential loading pathway. There is lack of a comprehensive dataset for the Spokane River watershed resulting in uncertainty of the uplands area surrounding the Spokane River (Dilks 2016a).

Sub-surface soils are at risk of long-term contamination as a result of legacy and modern-day contaminant loading. High organic subsurface soil may act as a long-term reservoir of PCBs with a very low leaching rate or cycling rate to other parts of the environment and ecosystems of the Spokane River watershed. Mineral soils are resistant to the binding of PCBs.

There have been 31 cleanup sites identified that may be leaching PCBs to the Spokane River by way of groundwater. Of these sites, 23 have confirmed PCB releases to soils – 13 have been cleaned-up with “No Further Action” required, and the remaining 10 are undergoing or

awaiting cleanup. Although these actions have reduced the overall PCB burden in the Spokane River watershed, there remains sub-surface leaching of PCBs from soils to groundwater feeding the Spokane River (LimnoTech 2016a).

5.4.1.2 River and Lake Sediment

River and lake bottoms are subject to deposition of organic and inorganic materials from both the surrounding terrestrial environment and the upstream aquatic environment. The composition of this substrate influences the ecological function and nutrient cycling in the system. Contaminants interact with sediments differently based on the physical and chemical characteristics of both the substrate and the contaminant of concern.

Historical PCB contamination of Spokane River sediments near Upriver Dam and Lake Spokane has been identified and monitored. Elsewhere, the Spokane River features sediment with minimal organics having a composition of gravel, cobbles, and boulders. This is congruent with the relatively high stream flow velocity through most of the River's reaches. Much of the Lake Spokane bed also contains low organic matter and is comprised of stones. Lake Coeur d'Alene and Latah Creek were similar in their sediment makeup containing low organic matter (Dilks 2016c).

5.4.1.3 Other Sources Areas

Contributions of PCBs from sources such as demolition of buildings, industrial activities, and unlawful disposal of consumer products containing PCBs are difficult to measure but may provide significant inputs of PCBs to the Spokane River. The long life of PCBs in the environment and their prolific use in building materials and electrical devices makes them likely candidates for long-term leaching (LimnoTech 2016). Although there are no known current or historic major industrial producers of PCBs in the Spokane River watershed, spills, on-site disposal, and volatilization of PCB-containing materials from industrial sites remain possible pathways for PCBs to enter the River (LimnoTech 2016).

5.4.2. Direct Delivery Mechanisms

PCBs are discharged to the Spokane River through a number of mechanisms (Dilks 2016a, LimnoTech 2016a, Dilks 2016c). Direct loading sources include:

- Upstream loading from Lake Coeur D'Alene – because the Spokane River is mainly fed by Lake Coeur D'Alene, this represents a major source of PCBs to the River due to the large volume of water it contributes.
- Tributary inputs – the two main tributaries to the Spokane River in the study area contribute PCBs to the Spokane River. Little Spokane River contributes more PCBs

than Latah Creek. Deep Creek becomes dry in the lower reaches so is not a source of water or PCBs to the Spokane River (Serdar et al. 2011, LimnoTech 2016a).

- Groundwater inputs from contaminated soil areas represent a source of PCBs to the Spokane River.
- Stormwater and CSOs direct PCBs in overland runoff and municipal sanitary sewer systems to the Spokane River.
- Discharges from municipal and industrial WWTP contribute to PCB loadings into the Spokane River. There are a number of industrial and municipal WWTP upstream of the City of Spokane's RPWRF, which is the largest treatment plant in the region. The RPWRF facility was constructed in 1958 with primary treatment. It was subsequently upgraded to include secondary treatment and disinfection. RPWRF has a capacity of 150 million gallons but on average treats 34 million gallons daily with all effluent discharged to the Spokane River (Dilks 2016a).
- Other PCB discharges include releases from fish hatcheries (wastewater and fish releases), resuspension of PCBs in bottom sediments, and atmospheric deposition.

5.5. Environmental Fate and Bioaccumulation of PCBs

5.5.1. PCB Transport within the Spokane River

The initial source of PCBs to the Spokane River is Lake Coeur d'Alene. Lake Coeur d'Alene contains PCBs which flow through the Spokane River to the Columbia River. At various locations along the Spokane River, there are additional inputs of PCBs to the River. These inputs include 16 known sources that discharge PCBs into the River. After being released into the River, PCBs are subject to a number of processes that control the environmental "fate" of PCBs in the River. One important process is the dissolution of the PCBs in the River water and the subsequent distribution of PCBs between the water and the sediments in the River. A second process is the downstream movement of water-dissolved and particle-bound PCBs as a result of the river flow rate. In sections of the River with a high flow rate, this process is very important and can quickly transport PCBs downstream. In sections of the River (e.g. Lake Spokane) with slow flow rates, this downstream hydrodynamic transport process is slower than in the river sections with high flow rates. Also, slow flow rates facilitate deposition of particle-bound PCBs into bed sediments. Deposited PCB contaminated sediments can build-up to form reservoirs of PCBs that can act like an internal source of PCBs for many years. PCBs can also evaporate from surface water into the atmosphere. However, in rivers this process tends to be of minor importance as the surface area of a river is

relatively small and PCBs in the water are bound to a high degree to sediment particulate matter and hence are unavailable for evaporation. PCBs are very stable compounds and known to degrade very slowly. For this reason, PCBs are referred to as Persistent Organic Pollutants (or POPs) under the UN Stockholm Convention on Persistent Organic Pollutants (UNEP 2001). Persistent means that PCBs last a long time and are not quickly broken-down. In riverine sections of the Spokane River, the fate of PCBs is therefore largely controlled by the water flow rates of the River. Evaporation and degradation do not play a significant role. In Lake Spokane, the slower flow rate means a slower removal of PCBs while evaporation and degradation play a slightly greater role than in the riverine sections of the River. More important is the deposition of sediments in Lake Spokane that provides historical deposits of PCBs that may be slow to dissipate.

5.5.2. PCB Bioaccumulation in Organisms

Because PCBs are very hydrophobic and lipophilic, PCBs are highly susceptible to uptake and bioaccumulation in aquatic organisms. Aquatic organisms, including algae, zooplankton, invertebrates and fish are all known to take up PCBs from water and to store PCBs in their fats.

The direct uptake of PCBs by aquatic organisms from the water is often referred to as direct uptake or bioconcentration and involves the uptake of PCBs from water via the respiratory area of aquatic organisms (e.g. gills in a fish). The uptake of PCBs from water is similar to the uptake of oxygen from water in fish. Within aquatic organisms, diffusion and blood flow (in certain organisms) distribute the PCBs throughout the tissues of the organism including the eggs of sexually mature female fish. Transfer of PCBs into eggs provides a pathway for inter-generational transfer of PCBs (Russell et al. 1999). Because many PCBs are not degraded in aquatic organisms and only transfer back to the water very slowly (because of their hydrophobicity), bioconcentration causes concentrations of PCBs in the organisms to exceed those in the water by many fold. The ratio of the concentration of PCBs in a particular aquatic organism (e.g. fish) and that in the water is called the bioconcentration factor. Bioconcentration factors have been measured in many laboratory tests (Arnot and Gobas 2006) and mathematical models exist to estimate bioconcentration factors (Thomann et al. 1992a, Thomann et al. 1992b, Arnot and Gobas 2004). It is important to stress that bioconcentration is a reversible process. If the concentration of PCBs in the water declines, so does the concentration of PCBs in the fish. There can be lag-phase between the declines in concentration in water and fish, especially when the concentration decline is rapid and/or the fish are large. However, over time, concentrations of PCBs in fish will reflect those in the water.

The uptake of PCBs from food items is referred to as indirect uptake or dietary bioaccumulation or biomagnification. Dietary bioaccumulation specifically refers to the uptake of substances like PCBs via the gastro-intestinal tract. Dietary bioaccumulation of PCBs involves the ingestion of PCB-contaminated food items. After ingestion, food digestion releases the PCBs from the food matrix. The PCBs can then diffuse through intestinal membranes into the organism. Within organisms, PCBs are distributed throughout the organism through a combination of molecular diffusion and advective transport processes. In higher-level organisms (e.g. fish), blood flow transports PCBs, first to the liver and then throughout all tissues and organs of the organism. The initial transport of PCBs and other substances from the intestinal tract to the liver is often referred to as a “first pass effect”. This first pass effect plays an important role in the uptake of substances in higher level organisms. If the substance can be broken down or biotransformed in the liver, then the distribution of the substance in the organism can be reduced. However, many PCB congeners resist biotransformation and are biotransformed at very low rates. As a result, the great majority of PCB congeners absorbed through the diet are distributed throughout the organism. Indirect uptake of PCBs also causes PCBs to biomagnify. Biomagnification is a phenomenon where concentrations of PCBs in the lipids of organisms attain levels that are greater than those in the lipids of ingested food. Biomagnification does not occur if the ingested substance is quickly biotransformed in the organism. However, the rate of biotransformation of many PCB congeners is so slow that certain PCBs biomagnify to a high degree. Biomagnification is of toxicological concern because it amplifies the concentration of the chemical in organisms with increasing trophic level. Dietary bioaccumulation of PCBs has been observed in numerous laboratory tests and field studies (Arnot and Quinn 2015) and mathematical models of this process are available and used (Arnot and Gobas 2004).

In food webs, PCBs are transferred from predator to prey. This is called food-web transfer or trophic transfer. Food web or trophic transfer of PCBs, which is the distribution of PCBs throughout all organisms of aquatic food webs, is the result of successive trophic interactions, where one organism preys on other organisms. The complexity of predator-prey interactions produces a set of complex pathways that distribute the PCBs through a food web. While specific pathways are hard to specify, there is a general transport of PCBs from lower trophic levels to higher trophic levels. These pathways can be characterized and measured by trophic magnification factors (TMFs). TMFs of PCBs have been studied in many aquatic systems (Mackintosh et al. 2004, Walters et al. 2011, Walters et al. 2016). While there is variability in reported TMF values, TMFs of many PCB congeners have been found to be greater than one. This indicates a general increase in the concentration of PCBs in organisms with increasing trophic level.

The combination of direct uptake, indirect uptake, and food web transfer provide pathways for PCBs to move from the water and sediments of the Spokane River to all aquatic species in the Spokane River system. All of these processes are reversible. This means that a reduction on the concentration of PCBs in water and/or sediments of the River can be expected to result in similar reductions in the concentration of PCBs in all organisms of the food web. There can be a lag-phase between the decline in PCB concentration in the water and the decline in in PCB concentrations in organisms. However, over time, concentrations of PCBs in aquatic organisms will adapt to reflect those in the water and sediment that they interact with.

6. DEVELOPMENT OF OPINIONS

6.1. Approach

6.1.1. Relationship between PCB Inputs and Concentrations of PCBs in Water, Sediment and Fish

The basic relationships between the inputs of PCBs into the Spokane River and the resulting concentrations of PCBs in water, sediment and aquatic biota is controlled by the Laws of Conservation of Mass. These relationships are often characterized in mathematical form and referred to as mass balance models. At any location of the River, the change of mass of PCB over time is the result of inputs and removals. Mathematically, this can be described as:

$$dM_{W,i}/dt = I - \sum k_{W,j} \cdot M_{W,i} \quad (1)$$

- where $dM_{W,i}/dt$ (g/d) is the change in the mass of PCB in the water of the Spokane River over time t at any particular location i of the River;
- I is the total combined input of PCBs (g/d) at location i ;
- $\sum k_{W,j}$ is the sum of all removal rates ($k_{W,j}$) in units of the fraction of mass of PCBs removed from the water at location i per unit of time (e.g. 1/day); and
- $M_{W,i}$ is the mass of PCBs in the water (g) of the Spokane River at location i .
- The subscript j refers to the number of removal processes that act on the PCBs and includes downstream flow, evaporation, degradation and any other loss processes that may apply.

If the input and loss processes remain constant over time, then $dM_{W,i}/dt$ approaches zero, which is a condition that is referred to as steady-state, and $M_{W,i}$ can be found as:

$$M_{W,i} = I / \sum k_{W,j} \quad (2)$$

Dividing the mass of PCBs in the water by the volume of water at location i ($V_{W,i}$), then provides a simple equation that relates the concentration of PCBs in the water at location i ($C_{W,i}$) to the total inputs of PCBs to the water at location i :

$$C_{W,i} = I / (V_{W,i} \cdot \sum k_{W,j}) \quad (3)$$

This equations states that the concentration of PCB in water at location i at steady-state is a simple linear function of the combined PCB inputs at location i . **In other words, if, for example, inputs of PCBs go down by 50%, so does the concentration of PCBs in the water, given sufficient time for steady-state to be reached and assuming river conditions (e.g. flow rates) remain the same.** This equation is very useful, because it allows us to calculate reductions in the concentrations of PCBs in water from reductions of PCB inputs to the River in a fairly simple manner.

The same laws of conservation of mass can be used to derive similar relationships for concentrations of PCBs in water, sediments and fish tissue.

The basic relationship between the masses of PCBs in the water and sediments at any location i of the River is:

$$dM_{S,i}/dt = k_{WS} \cdot M_{W,i} - \sum k_{S,n} \cdot M_{S,i} \quad (4)$$

- where $dM_{S,i}/dt$ is the change in the mass of PCBs (g/d) in the sediment of the Spokane River over time t at any particular location i ;
- k_{WS} is the rate of transfer of PCBs from the water to the sediments, expressed as the fraction of the mass of PCB in the water transferring to the sediments (1/day); and
- $\sum k_{S,n}$ is the sum of all removal rates $k_{S,n}$ in units of the fraction of mass of PCBs removed from the sediment at location i per unit of time (1/day); and
- $M_{S,i}$ is the mass of PCBs in the sediment (g) of the Spokane River at location i .

- The subscript n refers to the number of removal processes that act on the PCBs in the sediments and includes diffusion, accretion, degradation and any other loss processes that may apply.

If the transfer rates k_{ws} and $\Sigma k_{s,n}$ remain constant over time, then $dM_{s,i}/dt$ approaches zero over time (i.e. steady-state), and $M_{s,i}$ can be found as:

$$M_{s,i} = (k_{ws} / \Sigma k_{s,n}) \cdot M_{w,i} \quad (5)$$

Dividing the mass of PCBs in the water and sediments by their respective volume $V_{w,i}$ for water and $V_{s,i}$ for sediment at location i, then generates:

$$C_{s,i} = (k_{ws} / \Sigma k_{s,n}) \cdot (V_{w,i} / V_{s,i}) \cdot C_{w,i} \quad (6)$$

This equation states that at steady-state, the concentration of PCB in sediment at location i is a simple linear function of the concentration of PCBs in the water at location i. **Hence, if, for example, the concentration of PCBs in the water declines by 50%, then, given sufficient time for steady-state to be reached and river conditions remaining the same, the concentration of PCBs in the sediments will also decline by 50%.**

The relationship between the concentration of PCBs in fish and other aquatic organism in the River and the concentration in the water and/or sediments at any location i of the River can be expressed in a similar manner as those for sediment and water, but is somewhat more complex because organisms can take up PCBs directly from the water, sediment (for sediment ingesting organisms) and consumption of prey. Refer to Arnot and Gobas (2004) for a full account of the mathematical treatment of these relationships. One of the key features of the relationship between the concentration of PCBs in fish and other aquatic organism of a food web and the concentration in the water and/or sediments is that the relationships are linear in nature. This means that an increase or decrease in the concentration of PCBs in water or sediments is matched by a proportional increase or decrease in the concentration of PCBs in the aquatic organisms over time.

The main implication of the current understanding of the fate of PCBs in aquatic environments with respect to the effects of changes in PCBs inputs into the Spokane River on the concentrations of PCBs in fish of the River is that concentrations of PCBs in fish follow a linear relationship with PCB inputs in the River. Hence, declines in PCB discharges to the Spokane River can be expected to result in proportional declines in concentrations of PCBs in fish of the Spokane River. The response of the concentrations of PCBs in fish to reductions in

PCB inputs to the River is not immediate. Through detailed environmental fate and bioaccumulation modelling it is possible to assess the length of time it takes for concentrations of PCBs in the River to fully adapt to the change in PCB inputs into the River. This type of modelling was not done for this analysis. However, in much of the Spokane River (with the exception of Lake Spokane) river flow rate is high and fine depositional sediments are minimal. This indicates that the concentrations of PCBs in water and sediments can be expected to respond quickly to changes in PCB inputs. Concentrations of PCBs in fish will respond more slowly than concentrations of PCBs in water. However, even in large fish, loss rates of PCBs from fish can be expected to be in the range of 1% per day, suggesting that concentrations of PCBs in fish can effectively reach (i.e. be within 5% of) their new values in about $3/0.01$ or 300 days. These estimations indicate that in much of the Spokane River, concentrations of PCBs in water, sediment and fish can be expected to respond to PCB emission reductions in a reasonable length of time.

6.1.2. Conceptual Model

A simplified representation of the link between PCB inputs to the Spokane River and the resulting PCB concentrations in water, sediments and fish is shown in **Figure 6**. **Figure 6** represents a section of the River that receives PCB inputs from upstream, City of Spokane sources, and other non-City of Spokane sources, resulting in concentrations of PCBs in water, sediments and fish that reflect these loadings. PCBs are also transported downstream to the next river section. Within each medium of the river (e.g. water, sediment, fish species), the mass balance model assumes that contaminants are evenly distributed, within a given river section, and that the different environmental media are homogenous.

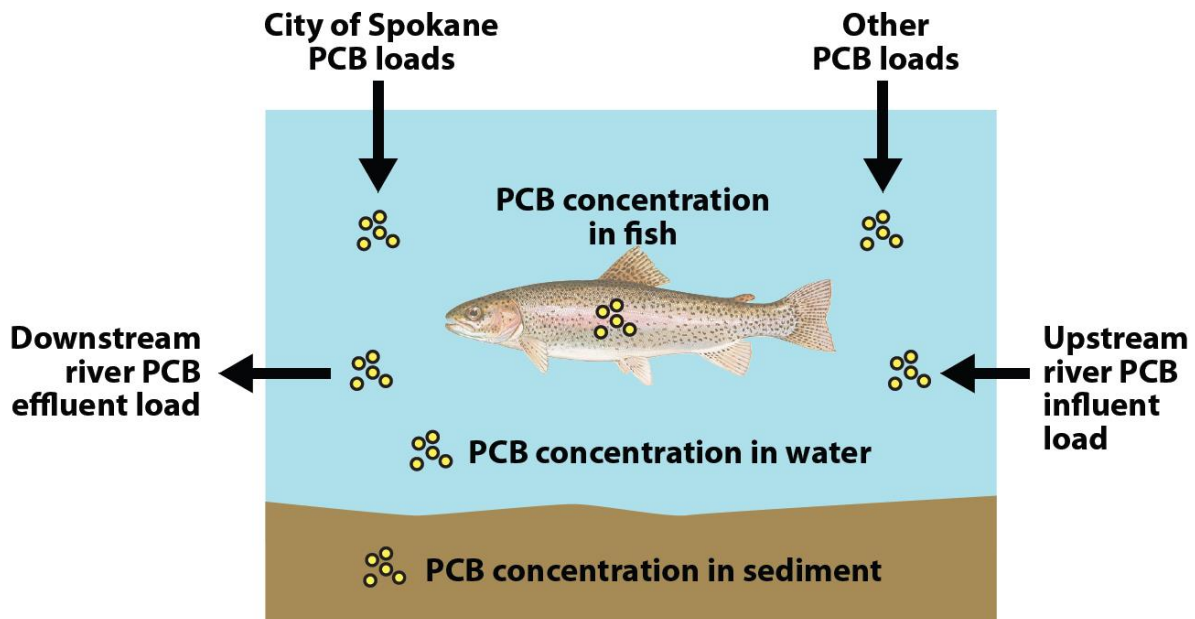


Figure 6: Diagram of PCB inputs and concentrations of PCBs in water, sediment and fish.

For many of the analyses conducted in this report, the Spokane River has been divided geographically into several sections, which are described in [Table 5](#). In general, these river sections were delineated by structural features in the River, such as dams, or by jurisdictional boundaries, such as the Idaho-Washington Stateline. Many of the studies investigating PCB concentrations in the Spokane River used a similar spatial division as the one used in this report. A map showing the spatial Spokane River sections is presented as [Figure 7](#).

Table 5: Spokane River sections and river mile ranges.

<i>River Section</i>	<i>River Mile Range</i>	<i>Under City of Spokane Influence?</i>
<i>Above Stateline</i>	112-96.1	No
<i>Above Upriver</i>	96.1-80.2	No
<i>Above Monroe</i>	80.2-74.0	Yes
<i>Above Nine Mile</i>	74.0-58.1	Yes
<i>Lake Spokane</i>	58.1-33.9	Yes
<i>Above Little Falls</i>	33.9-29.3	Yes
<i>Spokane Arm</i>	29.3-0	Yes

The primary area of focus of this report is between Stateline (RM 96.1) and Little Falls Dam (RM 29.3). PCB inputs from the City of Spokane enter between Upriver Dam (RM 80.2) and Nine Mile Dam (RM 58.1), thus the river sections Above Monroe (RM 80.2-74.0) and all those below, are under the influence of the City of Spokane's PCB discharges. While Spokane Arm (RM 29.3-0) is influenced by discharges from the City of Spokane sources, PCB inputs have not been fully characterized in this section because of a lack of data. Therefore, Spokane Arm has not been included in the predictive modelling contained in this report. Above Upriver (RM 96.1-80.2) represents the immediate upstream reference for the City of Spokane's discharges. PCB loadings from upstream of the City of Spokane were quantified at the Trent Avenue Bridge station (RM 85.3), located within the Above Upriver compartment (**Figure 7**).

Figure 8 shows the spatial river sections described above, combined with box models representing the reaches of interest, and identifies relevant PCB source locations (i.e. downstream of Trent Avenue), which are further described in **Section 6.2.1**. PCB loads at Trent Avenue include a combination of PCBs originating from Lake Couer d'Alene, as well as other sources entering upstream reaches of the Spokane River. While several different fish species were collected in different sections of the River, **Figure 8** shows the three fish species most commonly collected from the Spokane River for PCB studies: Mountain Whitefish, Rainbow Trout and Largescale Sucker.

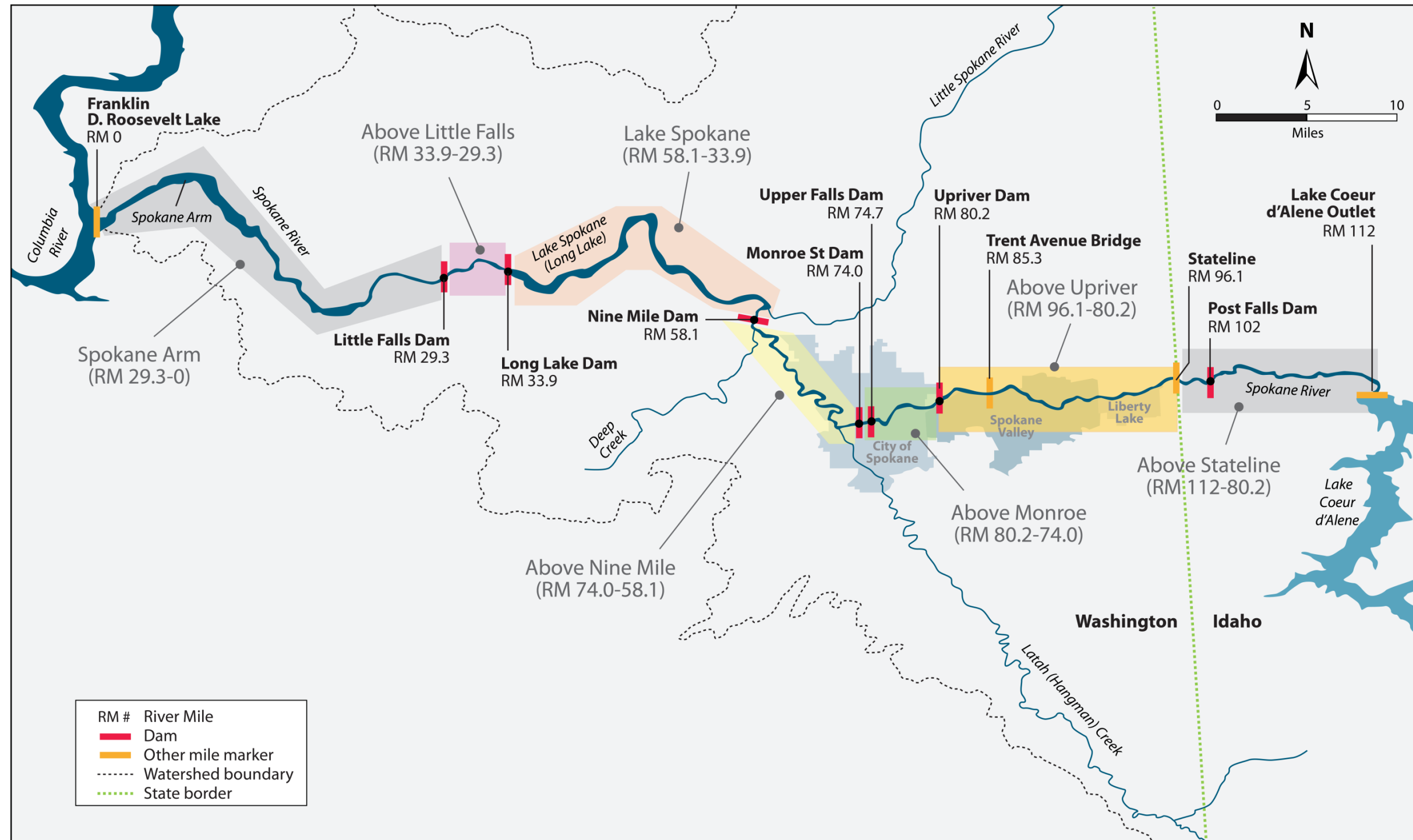


Figure 7: River sections of the Spokane River.

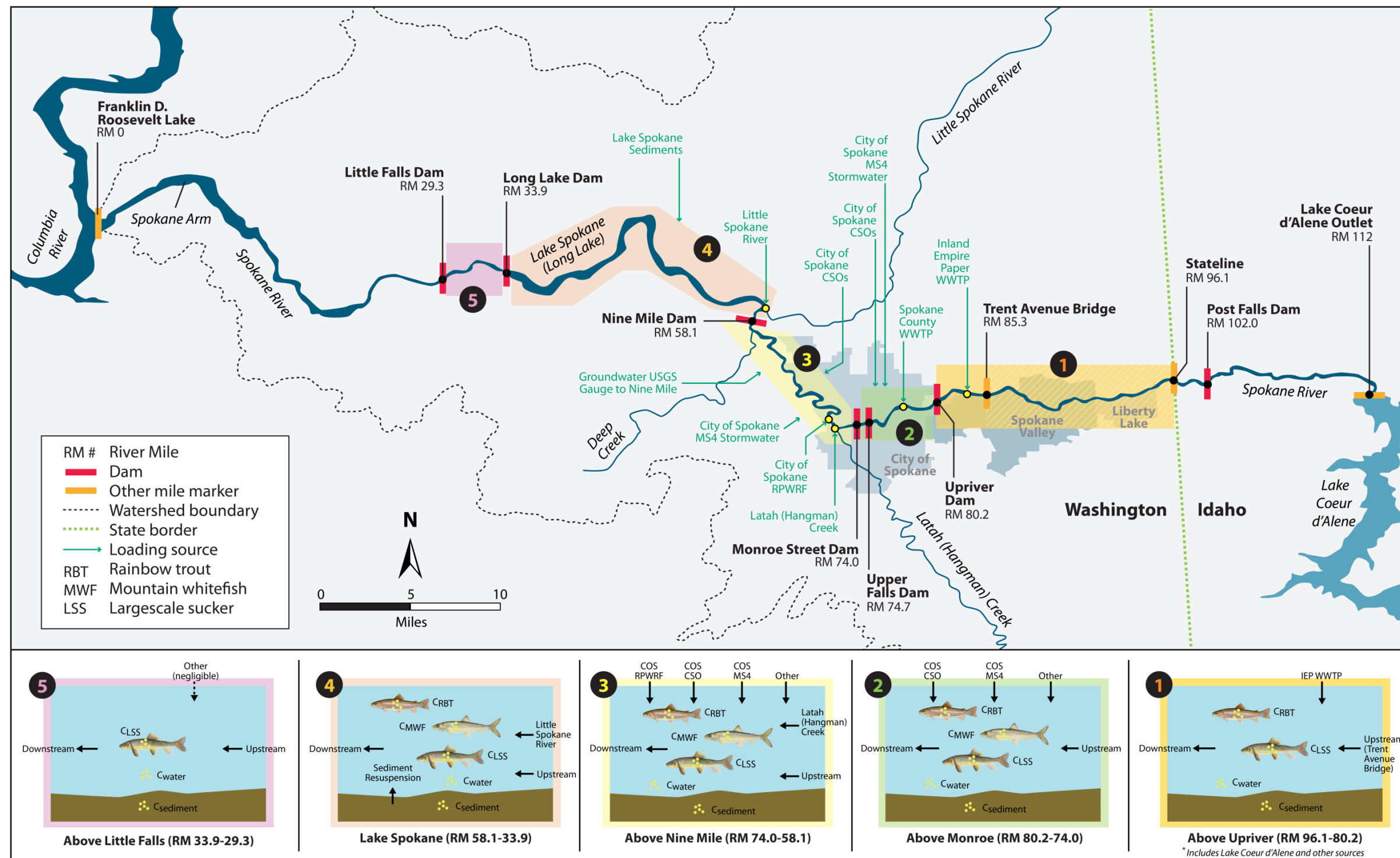


Figure 8: Conceptual model of the Spokane River.

6.1.3. Time Period Scenarios

Different time periods of interest were included in this report to address the questions of interest. These include:

- i. **Baseline Period (2003-2007):** This period corresponds to 2003-2007, before City of Spokane began upgrading the MS4 stormwater basins to reduce PCB discharges to the Spokane River. This period overlaps with the investigation period for the PCB source assessment study of the Spokane River (Serdar et al. 2011).
- ii. **Intermediary (2012):** An intermediary time period of 2012 was included in the analysis to represent conditions during the latest comprehensive study on PCB concentrations in fish from the Spokane River (Seiders et al. 2014). Because the City of Spokane made improvements to their facilities after 2012, the 2012 scenario was used as a reference point to estimate current (2018) and future concentrations of PCBs in fish.
- iii. **Current Period (2018):** The current period corresponds to 2018, and includes recent PCB loadings information (2014-2018) and recent PCB concentration data (range of 2013-2018; see [Table 6](#) for details) considered representative of current conditions. This scenario represents the period after existing improvements to the City of Spokane systems have been made.
- iv. **Future Scenario (2030):** A future time period scenario represents projections of the concentrations in water, sediment and fish to 2030 as a result of different remedial options for further upgrading the City of Spokane facilities and systems.

A summary of these time period scenarios, and concentration data representing these periods is provided in [Table 6](#).

Table 6: Loadings scenarios based on time periods of interest.

<i>Scenario</i>	<i>PCB Loadings Information</i>	<i>PCB Fish Data</i>	<i>PCB Sediment Data</i>	<i>PCB Surface Water Data</i>
Baseline Period (2003-2007)	Corresponds to PCB source assessment in Spokane River (Serdar et al. 2011), prior to City of Spokane system upgrades.	2001-2005	2003-2004	2000, 2003
Intermediary (2012)	Loadings information was developed for the 2011-2012 time period, corresponding to most recent comprehensive fish study (2012) (Seiders et al. 2014).	2012	N/A	N/A
Current Period (2018)	Loadings information developed for the 2014-2018 time period to represent current conditions after implementation of existing City of Spokane system upgrades.	2014 (carp) 2018 ^{a,b} (estimated)	2013-2018	2016-2018
Future Scenario (2030)	Modelled scenarios project City of Spokane loadings to 2030 based on different remedial options.	2030	2030	2030

^a A 2016 study by Wong (2018) that collected only 1-year old Rainbow Trout from Lake Spokane, 4- months after hatchery release, was not included in the “current” dataset. This is because the 2016 trout were younger and smaller than those collected in earlier fish studies.

^b 2018 PCB concentrations in fish are predicted from 2012 data; see [Section 6.2](#) for details.

6.2. Methods

In order to investigate the effect of past and future reductions in PCB discharges by the City of Spokane on concentrations of PCBs in fish of the Spokane River, three analyses were conducted.

6.2.1. Analysis I: Compilation and Analysis of PCB Discharge Rates into the Spokane River

Information on PCBs loadings into the Spokane River was obtained from Dilks (2019) and Michael Baker International (2019). These references provided in-River loading estimates, as well as PCB discharge rates for City of Spokane facilities and other industrial, municipal and non-point sources (e.g. groundwater and stormwater). This information was used to develop a PCB mass balance based analysis for the Spokane River from Trent Avenue Bridge (RM 85.3) to Long Lake Dam (RM 33.9). The Trent Avenue Bridge location receives PCB discharges from the headwaters of the Spokane River at Lake Coeur d'Alene (RM 112), as well as from all other point and non-point sources entering in Idaho and Washington, upstream of Trent Avenue. According to Dilks (2019), PCB loadings in the Spokane River are not expected to change substantially over the 4.6 mile stretch⁶ between Long Lake Dam (Rm 33.9) and Little Falls Dam (RM 29.3). Therefore, PCB loadings estimates at Long Lake Dam were assumed to represent PCB discharge rates up to Little Falls Dam (RM 29.3). Measurements of PCB discharges to the Spokane River below RM 29.3 are not available. The PCB loadings estimates by Dilks (2019) were used to characterize changes in PCB discharges to the Spokane River between baseline, 2012, current and future projected time periods ([Section 6.2.3](#)).

Dilks (2019) provided upper and lower bounds of PCB inputs from upstream (Trent Avenue, RM 85.3) and several of the sources discharging to the Spokane River above Long Lake Dam (RM 33.9) during the baseline (2003-2007), intermediary (2012) and current (2018) time periods. For many sources, the lower range of the loadings estimate was calculated using water concentration data for which non-detected PCB congeners were assigned a zero concentration in the summation of all measured PCB congeners. The upper range was

⁶ Between Long Lake Dam (RM 33.9) and Little Falls Dam (RM 29.3) there is a Tribal Fish Hatchery on Chamokane Creek, a tributary of the Spokane River. Given that the Washington State fish hatchery on the Little Spokane River is a negligible contributor of PCBs to Spokane River (<1% of total load), it is expected that the Tribal Hatchery is minor contributor of PCBs to the Spokane River as well (Dilks 2019). Thus, although PCB sources downstream of Long Lake Dam have not been fully characterized, there is expected to be little change to PCB loadings in the Little Falls Pool reach between Long Lake Dam (RM 33.9) and Little Falls Dam (RM 29.3).

determined as the sum of PCB congener concentrations where the full analytical detection limit was assigned to represent the concentration of non-detected congeners. In some cases, a single, best estimate, PCB loading value was provided.

Relative changes in PCB loadings between time periods were calculated from the data provided by Dilks (2019). Because the City of Spokane has continued to make improvements to reduce PCB discharges in recent years (i.e. since the 2012 fish study), two scenarios were developed to estimate potential changes in PCB concentrations in fish between 2012 and present-day (2018). The first scenario was based on the relative change between the lower bound of the PCB loading rate provided by Dilks (2019) for 2018 compared to the lower bound of the PCB loading rate provided for 2012. The second scenario calculated the relative change between time periods using the upper bound of PCB loadings in both time periods.

Michael Baker International (2019) provided baseline (2003-2007), intermediary (2012) and current (2018) data on PCB loadings from the three City of Spokane sources: the RPWRF, 12 MS4 stormwater basins, and 20 CSOs, which were incorporated into Dilks (2019). Michael Baker International (2019) also projected PCB loadings from the three City of Spokane sources into the future (2030). For the City of Spokane sources, different future predictions were provided for the RPWRF and MS4 stormwater basins. These discharge estimates were combined into three scenarios representing different levels of treatment: maximum treatment (i.e. highest level of treatment); minimum treatment (i.e. lowest level of treatment) and an intermediary level of treatment.

To complete the estimates of future impacts of discharges on the Spokane River, it was assumed that the current-day PCB discharge rates for all non-City of Spokane sources provided in Dilks (2019) are maintained in the future. This assumption enabled the determination of the expected declines in PCB concentrations in fish, sediment and water, directly resulting from upgrades to the City of Spokane facilities and systems. Using the upper and lower estimates of PCB discharge rates for all non-Spokane sources, and the three possible treatment levels for the City of Spokane sources, six future scenarios were evaluated, as described in [Table 7](#). Scenario 1 results in the highest reduction of PCB discharges in the future, relative to current levels. Scenario 6 results in the lowest reduction of PCB discharges in the future, relative to current levels.

In addition to the above current and future scenarios, an additional hypothetical calculation was made to evaluate changes in loadings between time periods, under the condition that the PCB discharges from the City of Spokane remained constant at 2012 levels. This scenario was used to compare changes in loadings *with* City of Spokane implementing PCB loadings reductions after 2012 (i.e. status quo to 2018 and planned future treatment options) to

changes in loadings *without* City of Spokane implementing PCB loadings reductions after 2012. This hypothetical calculation also included both a lower bound and an upper bound scenario.

Table 7: Future scenarios investigating the effect of different levels of PCB treatment at City of Spokane facilities and considering lower and upper bound estimates of non-City of Spokane PCB loadings.

Scenario	Non-Spokane PCB Loadings Estimate Level	City of Spokane Facilities Treatment Level (PCB Discharge Level)
1	Lower bound	Highest treatment level (= lowest PCB discharges)
2	Upper bound	Highest treatment level (= lowest PCB discharges)
3	Lower bound	Medium treatment level (= mid-level PCB discharges)
4	Upper bound	Medium treatment level (= mid-level PCB discharges)
5	Lower bound	Lowest treatment level (= highest PCB discharges)
6	Upper bound	Lowest treatment level (= highest PCB discharges)

Because the City of Spokane MS4 and CSO basins discharge into two compartments of the Spokane River, loadings rates were divided between the Above Monroe stretch (RM 80.2-74.0) and the Above Nine Mile stretch (RM 74.0-58.1). The majority of loadings from the Spokane MS4 stormwater basins (73%), as well as the single RPWRF outlet (100%), discharge into the lower Above Nine Mile river reach. The majority (96%) of PCBs discharged to the River by the City of Spokane CSOs enter the upper Above Monroe reach. However, the CSOs discharge the lowest amount of PCBs of the three City of Spokane sources. To calculate future loadings, and reductions relative to current-day, discharges of the different MS4 and CSO basins were grouped as shown in **Table 8**, according to Michael Baker International (2019). PCB discharge rates for the different time periods and scenarios are provided in **Section 6.3.1**.

Table 8: City of Spokane MS4 stormwater basins and CSO outfalls discharging above and below Monroe Street Dam.

City of Spokane Source	Basins/Outfalls Discharging East of Monroe Street Dam (Above Monroe)	Basins/Outfalls Discharging West of Monroe Street Dam (Above Nine Mile)
MS4 Stormwater Basins	Washington, Superior, Union, Riverton, Howard, Lincoln, Greene, Mission	Rifle Club, Hollywood, Cochran, Kiernan
CSO Outfalls	CSO 33 to CSO 42	CSO 2 to CSO 26

6.2.2. Analysis II: Compilation and Analysis of Measured Concentrations of PCBs in Water, Sediments and Fish of the Spokane River

PCB concentrations in fish, surficial bottom sediments and in-river surface water of the Spokane River are used in this report. This section provides an overview of how these data were compiled and analyzed for this report, with **Attachment C** providing a more detailed description of the data analysis conducted by Azimuth Consulting Group (“Azimuth”). The following steps were taken to analyze the relevant PCB concentration data and information for the Spokane River:

- A literature review was conducted by Azimuth on studies from the Spokane River measuring PCBs in fish, sediments, and surface river water. This was used to identify original reports relevant to the Spokane River PCB data analysis.
- A project database was received from Baron & Budd’s consultants, Pacific Groundwater Group (“PGG”). Based on when datasets for different media were complete in the database, version 13 of the database (PGG 2019a) was used by Azimuth to analyze fish tissue concentrations of PCBs and version 18 (PGG 2019b) was used to analyze concentrations of PCBs in surface water and sediment.
- As part of a quality assurance/quality control (QAQC) process, the project database was compared with original studies to confirm accuracy and completeness by Azimuth. Much of the PCB concentration data originated from studies conducted by Ecology, which was imported to the project database from Washington’s EIM database. Some of the water data from the SRRTTF studies were directly imported into the project database.
- Studies included in the fish tissue, sediment and surface water datasets are shown in **Table 9**, **Table 10**, and **Table 11**, respectively (also see **Attachment C**). PCB

concentration data from all sections of the Spokane River were included in the analysis.

Table 9: List of studies included in the Spokane River fish tissue PCB dataset: study identification number (ID#), year sampled and references.

Fish Study ID#	Year	Reference(s)
DSER0002	1992	(Serdar et al. 1994)
AJOH0005	1993	(Davis and Serdar 1994, Ecology 1995)
AJOH0005	1994	(Johnson 1994a, Ecology 1995)
WSPMP93T	1993	(Davis et al. 1995)
AJOH0008	1996	(Johnson 1997)
AJOH0022	1999	(Johnson 2000)
RJAC002	2001	(Jack and Roose 2002)
DSER0010	2003	(Serdar et al. 2011)
DSER0010	2004	(Serdar et al. 2011)
WSTMP03T	2003	(Serdar et al. 2011)
DSER0016	2005	(Serdar and Johnson 2006)
WSTMP12	2012	(Seiders et al. 2014)
BERA0011	2014	(Era-Miller 2015a)
MIFR0003	2016	(Wong 2018)

Table 10: List of studies included in the Spokane River sediment PCB dataset: study identification number (ID#), year sampled and references.

Sediment Study ID#	Year	Reference
BHOP0001	1990	(Hopkins 1991)
DSER0002	1992	(Serdar et al. 1994)
AJOH0005	1993	(Ecology 1995)
AJOH0005	1994	(Ecology 1995)
SPOK9394	1993	(Ecology 1995)
SPOK9394	1994	(Ecology 1995)
DBAT0001	1994	(Batts and Johnson 1995)
AJOH0019	2000	(Johnson and Norton 2001)
DSER0010	2003	(Serdar et al. 2011)
DSER0010	2004	(Serdar et al. 2011)
UPRVRDAM	2003	(Anchor Environmental LLC 2005)
UPRVRDAM	2004	(Anchor Environmental LLC 2005)
UPRDAM2008	2008	(Ecology 2015)
2010 UPRIVER DAM MONITORING	2010	(Ecology 2015)
SRUW-SPOKANE*	2013	(Fernandez 2012, Borgias and Hamlin 2017, PGG 2019b)
CITYOFSPOKANEWW	2015	(PGG 2019b)
SEDCORE16	2016	(Mathieu 2018)
SWON0001	2018	(Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c)

*From project database; earlier (non-sediment) data reported and Quality Assurance Project Plan available.

Table 11: List of studies included in the Spokane River surface water PCB dataset: study identification number (ID#), year sampled and references.

Surface Water Study ID#	Year	Reference
SGOL001	2000	(Golding 2001)
DSER0010	2003	(Serdar et al. 2011)
BERA0009	2012	(Era-Miller 2014a)
BERA0009	2013	(Era-Miller 2014a)
BERA0012	2016	(Era-Miller and McCall 2017)
COMBINED IDAHO DATA	2014	(PGG 2019b)
COMBINED IDAHO DATA	2016	(PGG 2019b)
SRRTTF-2014	2014	(LimnoTech 2015)
SRRTTF-2015	2015	(LimnoTech 2016b)
SRRTTF-2016	2016	(LimnoTech 2017)
WHOB003	2016	(Hobbs et al. 2019)
WHOB003	2017	(Hobbs et al. 2019)
SRRTTF-2018	2018	(LimnoTech 2019)

- Concentrations of total PCBs in water and sediment and fish were calculated in the project database as the sum of all individual Aroclors or PCB congeners measured in a sample. To address certain PCB congeners or Aroclors that could not be detected (i.e. exhibited concentrations in the sample below the detection limit⁷) in a sample, concentrations of total PCBs in a sample were assessed using three methods, i.e.

⁷ These treatments were also applied to blank censored concentrations of PCBs in water, i.e. concentrations of PCB congeners in field samples that were less than 3x the concentration of PCB congeners in blank samples were treated as non-detects in the summation of total PCBs (see also [Section 5.3](#)).

- i. Individual congeners/Aroclors that were non-detected were assumed to make a zero contribution to the concentration of total PCBs. This provides a lower limit of the concentration of total PCBs.
 - ii. Individual congeners/Aroclors that were non-detected were assumed to contribute a concentration equal to half the detection limit to the concentration of total PCBs. This provides a mid-level estimate for the concentration of total PCBs.
 - iii. Individual congeners/Aroclors that were non-detected were assumed to contribute a concentration equal to the detection limit to the concentration of total PCBs. This provides an upper limit for the concentration of total PCBs.
- On PCB concentration data received from the database, Azimuth did further clean-up and sorting to prepare the data for analysis. Azimuth calculated additional parameters (e.g. lipid and organic carbon normalized concentrations), provided summary statistics (e.g., arithmetic averages and geometric means on multiple individual samples collected from the same river stretch and during the same time period) and performed additional statistical analyses (e.g. regression analysis between Aroclor on congener-based data, and temporal trend analyses on PCB concentrations in fish). See **Attachment C** for additional information.

PCB concentration data results are reported in **Section 6.3.2**.

6.2.3. Analysis III: Application of a Mass-Balance Approach to Assess the Effect of PCB Discharges by the City of Spokane on Concentrations of PCBs in Fish of the Spokane River

In this analysis, expected changes in the concentrations of PCBs in water, sediment and fish of the Spokane River are determined from the relative change in PCB discharges to the River between time periods, or following PCB emission control initiatives by the City of Spokane (derived in Analysis I). These relative changes in PCB loadings are combined with measured concentrations of PCBs in water, sediment and fish of the Spokane River (derived in Analysis II) to estimate:

- i. Due to a lack of recent fish data, current (2018) concentrations of PCBs in fish were calculated from 2012 fish data based on changes in PCB loadings that occurred between the intermediary (2012) and current time periods. Two scenarios were calculated as described in **Section 6.2.1**.

- ii. Future (2030) concentrations of PCBs in water, sediment and fish were calculated using anticipated PCB loadings reductions after further treatment/upgrades of the City of Spokane facilities/systems. These expected reductions were applied to recent concentrations of PCBs in water (2016-2018), sediment (2013-2018) and fish (2012⁸). Six scenarios were calculated as described in **Section 6.2.1**.
- iii. PCB concentrations in fish were predicted for the 2018 and 2030⁹ time periods under the hypothetical condition that PCB discharges from the City of Spokane remained constant at 2012 levels. Two scenarios were calculated (**Section 6.2.1**).

The calculation of the predicted concentration of PCBs (Analysis III) is based on the linearity in response of the concentration of PCBs to changes in the combined total inputs of PCBs into the River, which is controlled by mass balance principles (**Section 6.1.1**).

Since PCB inputs to the River vary spatially, calculations were made for each of the sections of the Spokane River separately (see **Table 12**). Although there may be differences in concentrations of PCBs within a river reach, depending on where PCB sources enter the reach, organisms such as fish tend to integrate PCB concentrations over larger spatial areas as they move within the reach. As described in **Section 5.1.4**, it is important to stress that fish movement is limited by dams in the Spokane River, often causing fish to remain within the reaches between dams.

Results of the calculation of current concentrations of PCBs in fish, as well as future concentrations of PCBs in water, sediments and fish are presented in **Section 6.3.3**.

⁸ The fish analysis was based on loadings changes between the 2012 time period and future (2030) scenarios.

⁹ We note that under the hypothetical condition where the City of Spokane's PCB discharges remain constant at 2012 levels, PCB concentrations in fish predicted for 2018 are the same as those predicted in the future (2030). This is because under the status quo assumption, only the City of Spokane PCB discharges are expected to be reduced in the future as a result of facility upgrades and treatment by the City of Spokane. Other sources of PCBs to the Spokane River are assumed to remain constant in the future at 2018 levels.

Table 12: Location of loadings source entry points in the Spokane River.

Loadings Source	River Mile	River Stretch Where Sources Enter
Upstream Spokane River at Trent Avenue Bridge [§]	85.3	Above Upriver (RM 96.1-80.2)
Inland Empire Paper WWTP	82.6	
Spokane County WWTP	78.5	Above Monroe (RM 80.2-74.0)
City of Spokane MS4 basins above Monroe St. Dam	74.0*	
City of Spokane CSO outfalls above Monroe St. Dam	74.0*	
Hangman (Latah) Creek	72.4	Above Nine Mile (RM 74.0-58.1)
City of Spokane RPWRF (WWTP)	67.4	
City of Spokane MS4 basins below Monroe St. Dam	58.1*	
City of Spokane CSO outfalls below Monroe St. Dam	58.1*	
Groundwater USGS Gauge to Nine Mile	58.1*	
Little Spokane River	56.3	Lake Spokane (RM 58.1-33.9)
Lake Spokane Sediments	33.9*	
Assumed negligible PCB sources between Long Lake Dam and Little Falls Dam	N/A	Above Little Falls (RM 33.9-29.3)
Uncharacterized below Little Falls Dam	N/A	

§ Trent Avenue Bridge includes PCB loadings originating from Lake Coeur d'Alene, as well as other point and non-point sources entering the River above RM 85.3.

*Approximate river mile or downstream extent of diffuse, non-point sources.

6.3. Results & Discussion

6.3.1. Compilation and Analysis of PCB Discharge Rates into the Spokane River

Studies and surveys conducted by Serdar et al. (2011), Parsons and Terragraphics Inc. (2007), and LimnoTech on behalf of SRRRTF (LimnoTech 2015, LimnoTech 2016a, LimnoTech 2016b, LimnoTech 2017, LimnoTech 2019), and the Expert Report of Dilks (2019), indicate that the 51 mile section of the Spokane River between Trent Avenue Bridge (RM 85.3) and Long Lake Dam (RM 33.9) receives inputs of PCBs from several sources. These include the three City of

Spokane sources, two tributaries (i.e. Latah/Hangman Creek, and Little Spokane River), a municipal WWTP, an industrial WWTP, groundwater inputs, and resuspension of PCBs from Lake Spokane sediments (**Table 13**). The upstream PCB loads at Trent Avenue Bridge include PCBs from Lake Coeur d'Alene, which feeds the Spokane River, as well as inputs from municipal, and industrial discharges, stormwater and groundwater, as documented in LimnoTech (2016a). Water from Lake Coeur d'Alene contains PCBs and is the largest source of water to the River and it is therefore expected to be a primary source of PCBs to the Spokane River, as described in Serdar et al. (2011), LimnoTech (2016a). Between Long Lake Dam (RM 33.9) and Little Falls Dam (RM 29.3) there is a Tribal Fish Hatchery on Chamokane Creek, a tributary of the Spokane River, which is expected to be a minor contributor of PCBs to the Spokane River (Dilks 2019). The three City of Spokane facilities are the focus of this opinion.

6.3.1.1 Baseline Time Period Analysis

For the 2003-2007 baseline period, Dilks (2019) estimated that by the time river water reached the area of the River influenced by the City of Spokane discharges, a total of 1148 to 1890 mg of PCB per day was added to the Spokane River. During this period, the City of Spokane added 129 mg PCB/d from stormwater (MS4) discharges, 36 mg PCB/d from CSO discharges and 194 mg PCB/d from the City of Spokane RPWRF. The combined discharge of PCBs by the City of Spokane during the baseline period amounted to 359 mg/d. Within and downstream of the City of Spokane sources, there were additional inputs of PCBs from Latah (Hangman) Creek, the Little Spokane River, groundwater, and Lake Spokane sediments at a combined rate of between 157 and 335 mg/d. Throughout the baseline period, the City of Spokane facilities contributions amounted to 22% (lower bound loading estimate) to 14% (upper bound loadings estimate) of the total known inputs of PCBs to the Spokane River. The PCBs in Spokane River upstream of the City of Spokane facilities at Trent Avenue station accounted for between 66% (lower bound loading estimate) to 71% (upper bound loadings estimate) of the total PCB loads in the River at Long Lake Dam (RM 33.9). Other sources such as Inland Empire Paper WWTP (2 to 3%), tributaries (5 to 10%) and groundwater in the Above Nine Mile reach (3 to 4%) contributed the majority of the remainder of PCBs added to the River.

6.3.1.2 Intermediary (2012) Time Period Analysis

For the 2012 time period, Dilks (2019) estimated that PCB loads present in the Spokane River upstream of the City of Spokane sources totalled 1166 to 1908 mg of PCB per day. These are higher than those estimated for the baseline period, mainly due to increased PCB loads from the Inland Empire Paper WWTP. The City of Spokane inputs in 2012 were lower than those

during the baseline period and totalled 159 mg PCB/d, with 47 mg/d discharged in stormwater, 9 mg/d from CSOs and 103 mg/d from the RPWRF. This represents a reduction in PCB discharges from the City of Spokane of $359 - 159 = 200$ mg/d (or 56%). Other sources between and downstream from the City of Spokane discharges were estimated to remain unchanged since the baseline period. Overall, PCBs discharged by the City of Spokane facilities comprised a smaller proportion of the total PCBs in the Spokane River in 2012 compared to the baseline period (i.e. approximately 7% [upper bound loading estimate] to 11% [lower bound loading estimate] of the total known PCB inputs). Spokane River PCB loads at the upstream Trent Avenue station comprised approximately three-quarters of the total PCB loads in the River at Long Lake Dam (RM 33.9).

6.3.1.3 Current (2018) Time Period Analysis

Between 2003-2007 and 2018, PCB discharges from upstream of the City of Spokane sources increased by 3 to 4% to between 1192 to 1939 mg PCB/d, largely because PCB discharges from Inland Empire Paper and the Spokane County WWTP were higher in 2018 than in the baseline period. However, between 2003-2007 and 2018, the combined discharge of PCBs by the City of Spokane sources fell from 359 mg/d to between 114 mg/d and 126 mg/d. The decline in PCB discharges by the three City of Spokane facilities between 2003-2007 and 2018 was therefore between $359 - 126 = 233$ mg/d and $359 - 114 = 245$ mg/d (or 65 to 68%). City of Spokane sources also discharged lower amounts of PCBs in 2018 (114 to 126 mg/d) compared to 2012 (159 mg/d). Inputs of PCBs downstream of the City of Spokane sources remained unchanged since 2003-2007 (i.e., 157 to 335 mg/d). In 2018, the City of Spokane sources accounted for only 5% (upper bound loadings estimate) to 8% (lower bound loadings estimate) of total PCBs discharged into the Spokane River. Consistent with the 2012 time period, upstream sources of PCBs at the Trent Avenue station represented approximately three-quarters of the total PCB loads in the Spokane River present at Long Lake Dam (RM 33.9).

6.3.1.4 Expected Changes in Concentrations between Baseline, 2012 and Current

Because of the linearity of the relationship between PCB inputs and resulting concentrations of PCBs in water, sediments and fish reached over time, it is possible to estimate the decline in the concentrations of PCBs in water, sediments and fish from the proportional decline in PCB loadings. Two figures illustrate the expected declines in concentrations of PCBs due to changes in PCB discharges between time periods, as a function of river mile: **Figure 9** shows the expected changes from baseline to current; and **Figure 10** shows the changes from 2012 and current (for predicting current PCB concentrations in fish). **Figure 9** shows that between RM 85.3 and 78.5, concentrations are expected to increase by 2.6 to 3.8% due to the

increases in PCB discharges from Inland Empire Paper and the Spokane County WWTP. The combined reductions of PCB discharges at the City of Spokane sources over the period between 2003-2007 and 2018 are expected to reduce concentrations of PCBs in water, sediment and fish by approximately 7.1 to 12% in sections of the River downstream of the City of Spokane facilities.

Figure 10 shows that differences in overall loadings (and expected concentrations) between 2012 and 2018 are small. PCB concentrations in media upstream from the City of Spokane (between RM 85.3 and 78.5) are expected to have increased by 1.6% to 2.2% due to increases in PCB discharges from Inland Empire Paper and the Spokane County WWTPs. Due to reductions in PCBs discharged by the City of Spokane between 2012 and 2018, PCB concentrations in media downstream of the City of Spokane sources are expected to be the same or slightly lower (i.e. <0.1% to 1.3% lower) in 2018 than those in 2012. The effect of PCB discharge reductions at the City of Spokane facilities on the concentrations of PCBs downstream from the City of Spokane, are largely off-set by upstream PCB loadings increases between 2012 and 2018.

Results of the hypothetical scenario, which explores the changes in PCB discharges to the Spokane River under the assumption that the City of Spokane did no further upgrades to the systems to reduce their PCB discharges after 2012, are provided in **Attachment C**. Under these conditions, PCB discharges to the River would have increased between 2012 and 2018 for all river sections downstream of RM 80.2 (i.e. by 1.6% to 2.2% in Above Monroe [RM 80.2-74.0], and 1.3% to 1.8% between RM 74.0 and 29.3). This demonstrates that, if the City of Spokane had not implemented system upgrades that reduced PCB discharges to the River, concentrations of PCBs in fish and other media would be expected to have increased between 2012 and 2018, due to increases in PCB discharges from other sources that occurred between these periods.

6.3.1.5 Future Predictions

Trapp (2019) projected future PCB loadings estimates for the City of Spokane facilities/systems for three different levels of treatment or remedial options. Trapp (2019) estimates that PCBs inputs by the City of Spokane can be expected to fall to combined rates between 26.66 mg/d and 27.59 mg/d. These values indicate that all three levels of treatment yield similar PCB discharges from the City of Spokane sources, with the RPWRF being the largest of the three sources (**Table 13**). The expected reductions in future PCB discharges by the City of Spokane constitute an approximately 4 to 5-fold decline compared to PCB discharges by the City of Spokane sources in 2018. These future PCB discharge rates also constitute an approximately 13-fold reduction in PCBs loads from City of Spokane since the

baseline time period. Based on these estimates, a reduction in the concentration of PCBs in water, sediments and fish can be anticipated.

Figure 11 (highest City of Spokane treatment level), **Figure 12** (medium City of Spokane treatment level), and **Figure 13** (lowest City of Spokane treatment level) illustrate the relative reductions in concentrations of PCBs that are forecasted in the future relative to 2018 levels, as a result of declines in PCB inputs due to additional PCB remedial efforts at the City of Spokane facilities. No reductions in concentrations of PCBs in water, sediment and fish are expected above RM 80.2 (Upriver Dam) because this section of the River is upstream of the City of Spokane sources and not affected by upgrades at the City of Spokane facilities. Reductions in concentrations of PCBs of between 0.8 to 1.3% are anticipated between RM 80.2 and 74.0 (Above Monroe) for all three levels of treatment.

Figure 11 to Figure 13 show that downstream of all of the City of Spokane facilities, between RM 78.5 and 58.1 (Above Nine Mile), concentrations of PCBs in water, sediment and fish can be expected to fall after 2018 by 4.5 to 6.0%, if the largest reductions in PCB discharges (i.e. higher level of treatment) are achieved, and by 4.4 to 5.9%, if the lower or mid-level reductions in PCB discharges (i.e. lower or mid-level of treatment) are achieved. In Lake Spokane and Little Falls Pool (RM 58.1 to 29.3), future concentrations are expected to be 4.2 to 5.9% lower than current, if the higher level of treatment is applied, and 4.1 to 5.9% lower than current, if the lower or mid-level of treatment is applied. These anticipated reductions in PCB concentrations assume that only PCB discharges at the City of Spokane facilities decline after 2018. If PCB discharge levels from other sources also decline, greater reductions in concentrations of PCBs can be expected. After modifications are realized, the City of Spokane will only contribute 1.2 to 1.9% (if the higher treatment levels are achieved) or 1.2 to 2.0% (if the lower or mid treatment levels are achieved) of the total estimated PCB loadings to the Spokane River.

Figure 14 to 16 show the changes in concentrations of PCBs in fish anticipated for the three future scenarios, relative to concentrations of PCBs in fish measured in 2012: **Figure 14** depicts reductions as a result of the highest City of Spokane treatment level, **Figure 15** for the medium treatment level, and **Figure 16** for the lowest City of Spokane treatment level. Due to increases in PCB discharges between 2012 and 2018 from non-City of Spokane sources upstream from the City of Spokane facilities, a slight (i.e. 0.7%) increase in the concentrations of PCBs in fish is predicted in the future in the Above Monroe stretch (RM 80.2 to 74.0), relative to 2012 levels. In the Above Nine Mile compartment (RM 74.0-58.1), concentrations of PCBs in fish in the future are expected to be 4.5 to 7.2% lower than those in 2012 for all levels of treatment. In Lake Spokane and Little Falls Pool (RM 58.1-29.3)

concentrations of PCBs in fish are expected to fall by 4.2 to 7.2% (highest treatment) or 4.2 to 7.1% (lowest and mid-level treatment).

Results of the hypothetical scenario, where future City of Spokane PCB discharge rates are maintained constant at 2012 rates, illustrate that PCB loadings to the River in the future would be expected to be 1.3% to 2.2% higher than 2012 levels, in all sections of the Spokane River between RM 74.0-29.3 (for both upper and lower-bound estimates **Attachment C**). This increase is due to increases in loadings between 2012 and 2018 from non-City of Spokane sources. The difference between the “no further treatment” and “planned treatment” conditions can be used to show the actual improvement in PCB loadings as a result of treatment by the City of Spokane. For example, in the Above Nine Mile reach (RM 74.0-58.1), the City of Spokane future treatment actually reduces PCB loadings to the Spokane River, relative to 2012 levels, by up to 9.0% (= maximum reduction with treatment [7.2%] + maximum increase without treatment [1.8%]) (**Attachment C**).

The anticipated reductions of PCB concentrations in water, sediments and fish from 2018/2012 levels can be used to estimate the concentrations of PCBs in water, sediments and fish that can be expected to be achieved over time. This involves assessing the concentrations of PCBs in water, sediments and fish in 2018/2012 and applying the reductions in expected concentrations estimated from the reductions in PCB discharge levels. The following section presents the compilation and analysis of concentrations of PCBs in water, sediments and fish of the Spokane River for the period of 1990 and 2018, for which measurements are available. This is followed by a section that includes the calculation of expected concentrations of PCBs in fish as a result of the treatment option considered by the City of Spokane.

Table 13: Loadings (mg/d) of PCBs discharged into the Spokane River from various sources for baseline (2003-2007), intermediary (2012), current (2018) and future scenarios (2030).

Loadings Sources/In-River Locations	River Mile	Lower Bound PCB Loadings 2003-2007 Scenario (mg/day)	Upper Bound PCB Loadings 2003-2007 Scenario (mg/day)	Lower Bound PCB Loadings 2012 Scenario (mg/day)	Lower Bound PCB Loadings 2012 Scenario (mg/day)	Lower Bound PCB Loadings 2018 Current Scenario (mg/day)	Lower Bound PCB Loadings 2018 Current Scenario (mg/day)	High Treatment \$ PCB Loadings - 2030 Future	Mid Treatment \$ PCB Loadings - 2030 Future	Low Treatment \$ PCB Loadings - 2030 Future
		Dilks (2019)	Dilks (2019)	Dilks (2019)	Dilks (2019)	Dilks (2019)	Dilks (2019)	MBI (2019)	MBI (2019)	MBI (2019)
Totals at Trent Avenue Bridge	85.3	1103	1845	1103	1845	1103	1845			
Inland Empire Paper WWTP	82.6	45.0	45.0	62.6	62.6	83.0	86.2			
Totals at Upriver Dam	80.2	1148	1890	1166	1907	1186	1931			
Spokane County WWTP	78.5	0	0	0.38	0.38	5.99	7.79			
City of Spokane MS4 u/s of Monroe St. Dam	74.0*	33.3	33.3	12.3	12.3	9.83	9.83	0	6.05E-05	8.12E-03
City of Spokane CSO u/s of Monroe St. Dam	74.0*	3.53	3.53	5.28	5.28	5.63	5.63	0	0	0
Totals at Monroe St. Dam	74.0	1185	1926	1184	1925	1208	1954			
Hangman (Latah) Creek	72.4	83.3	101.4	83.3	101.4	83.3	101.4			
City of Spokane RPWRF (WWTP)	67.4	194.0	194.0	102.7	102.7	71.2	83.8	26.64	27.53	27.53
City of Spokane MS4 u/s of Nine Mile Dam	58.1*	95.7	95.7	35.2	35.2	26.8	26.8	0	3.72E-04	0.031
City of Spokane CSO u/s of Nine Mile Dam	58.1*	32.4	32.4	3.65	3.65	0.25	0.25	0.022	0.022	0.022
Groundwater USGS Gauge to Nine Mile	58.1*	66.1	66.1	66.1	66.1	66.1	66.1			
Totals at Nine Mile Dam	58.1	1657	2416	1475	2234	1455	2232			
Little Spokane River	56.3	7.6	148.0	7.6	148.0	7.6	148.0			
Lake Spokane Sediments	33.9*	0.05	20.0	0.05	20.0	0.05	20.0			
Totals at Long Lake Dam	33.9	1664	2584	1483	2402	1463	2400			
Totals at Little Falls Dam	29.3	assumed same as Long Lake Dam		assumed same as Long Lake Dam		assumed same as Long Lake Dam				
Total City of Spokane Sources		358.9	358.9	159.1	159.1	113.6	126.3	26.66	27.55	27.59

Notes:
* Represents diffuse or multiple sources; approximate or lower River Mile limit is provided.
§ Three future PCB loadings levels for City of Spokane sources were based on: three PCB discharge rates for MS4 stormwater, two levels of treatment for the RPWRF, and one PCB discharge rate for CSOs.
MBI = Michael Baker International

In-river locations
City of Spokane sources

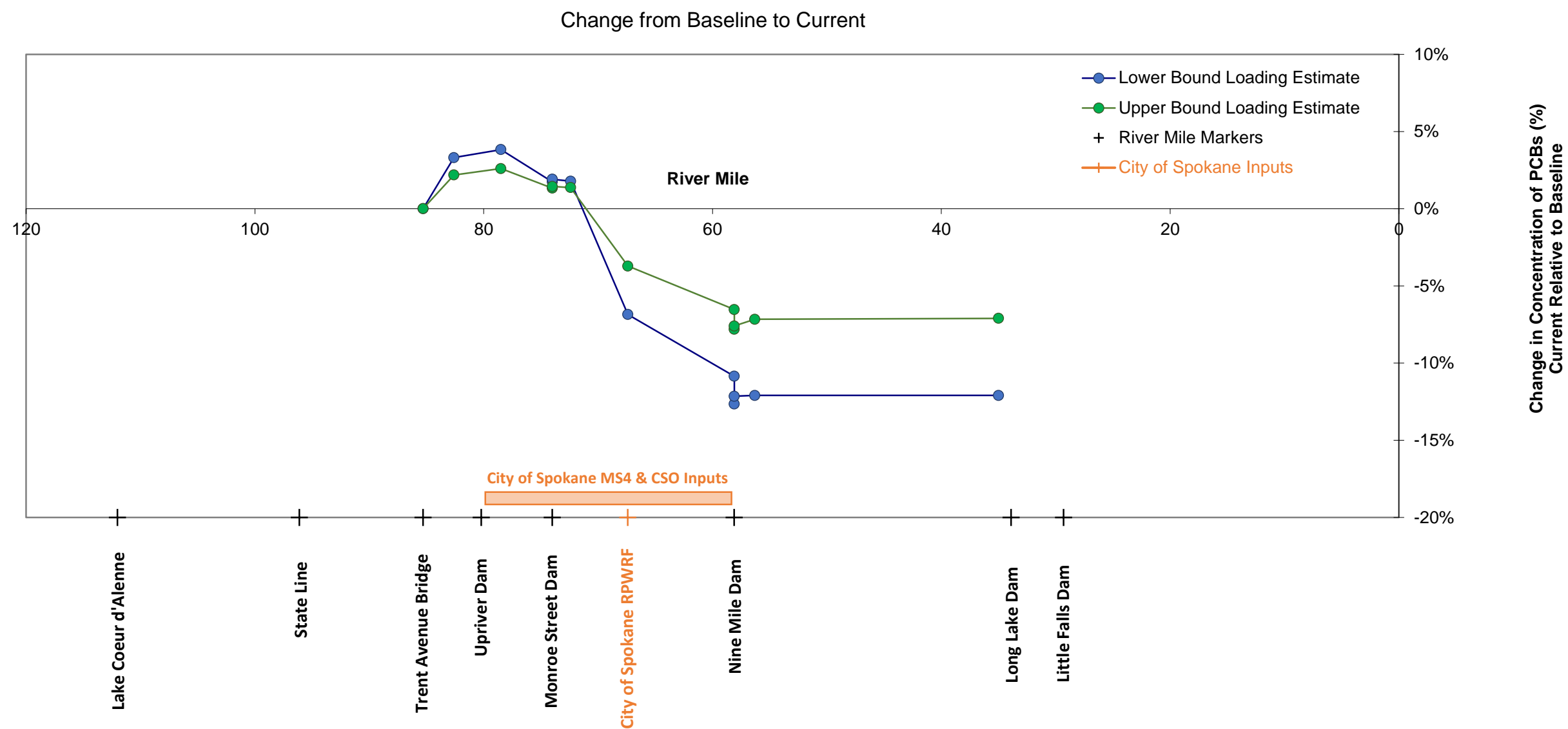


Figure 9: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River between 2003-2007 and 2018 as a function of river mile, based on changes in PCB discharges. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual expected changes in concentrations are expected to fall in between the blue and green lines.

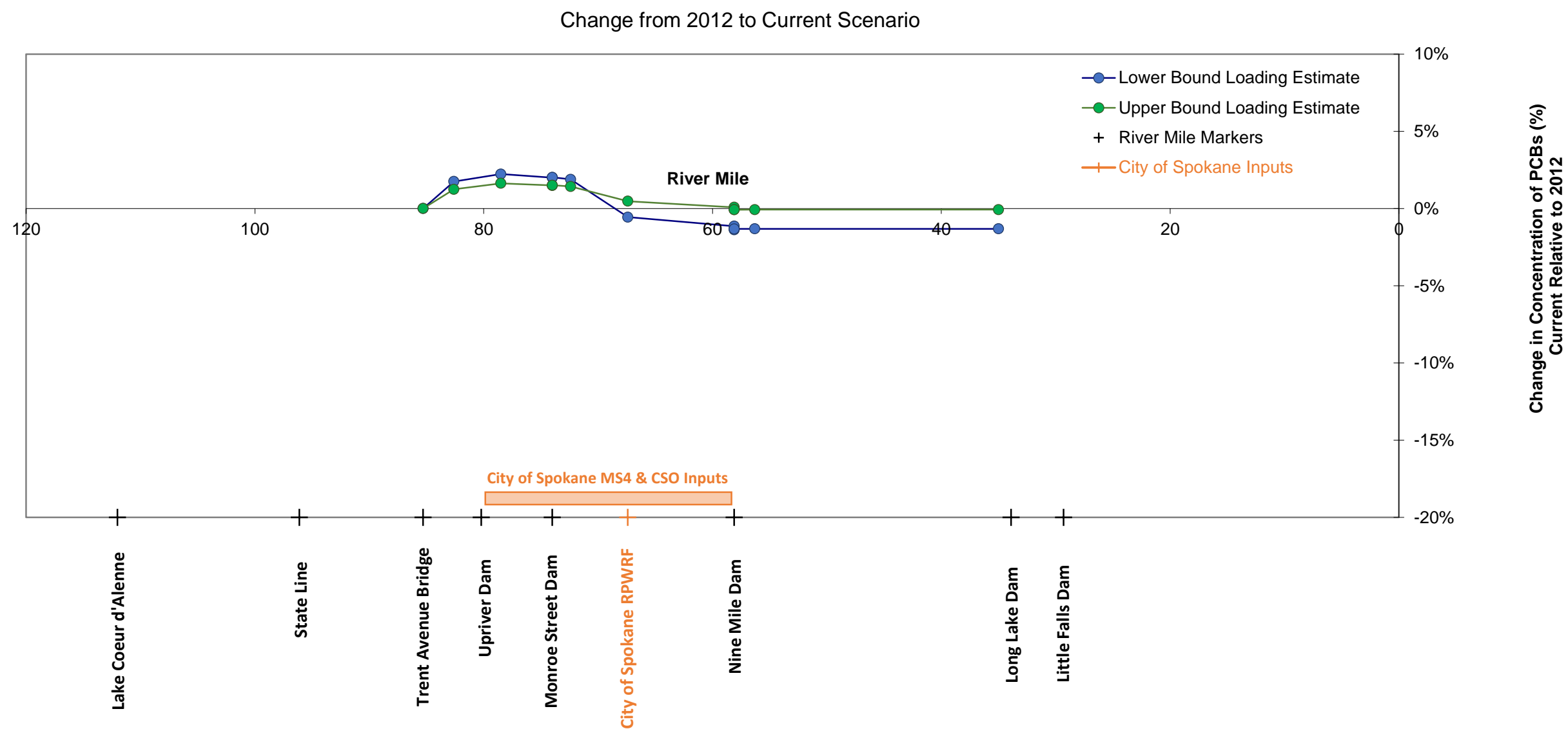


Figure 10: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River between 2012 and 2018 as a function of river mile, based on changes in PCB discharges. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual expected changes in concentrations are expected to fall in between the blue and green lines.

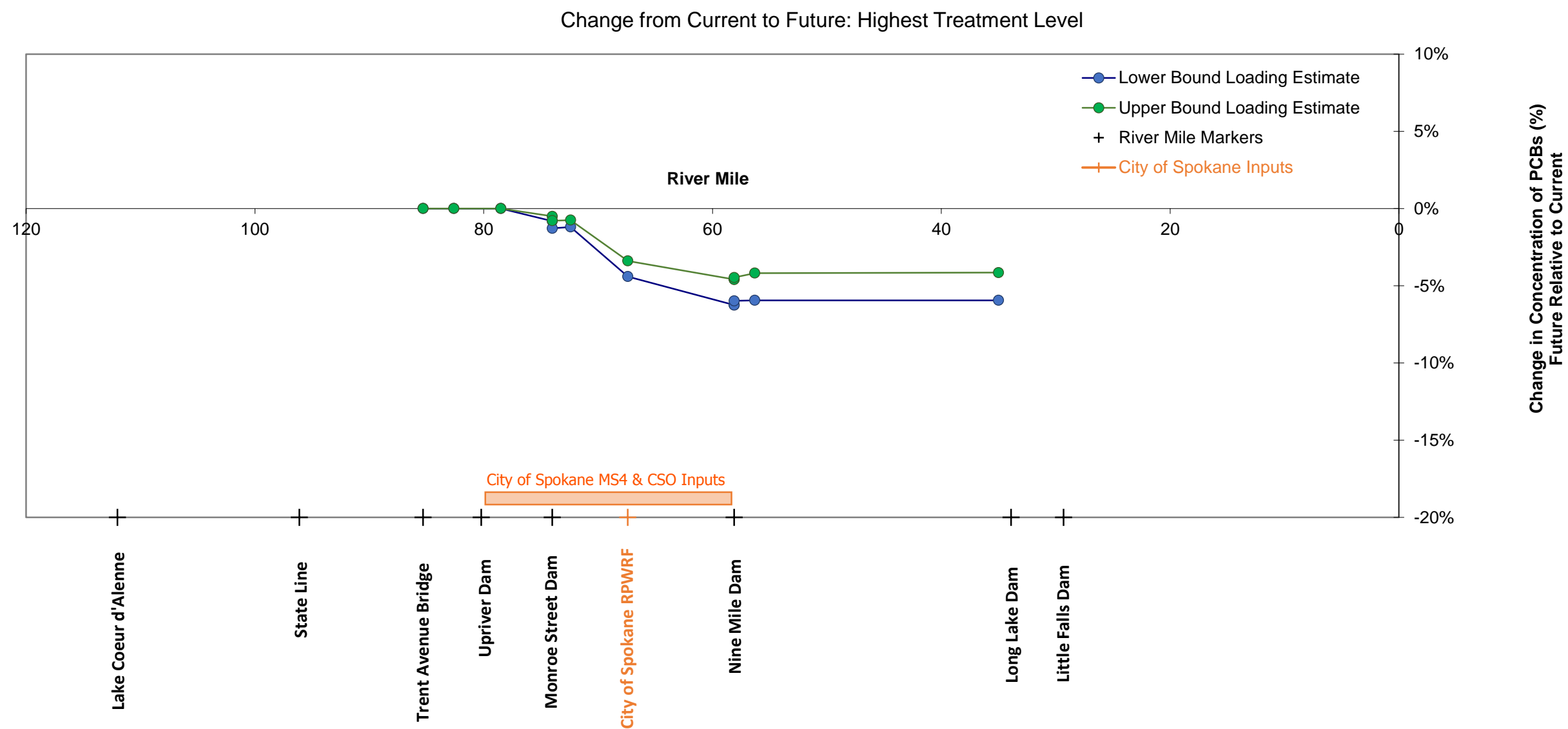


Figure 11: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2018 levels as a function of river mile in response to maximum treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the blue and green lines.

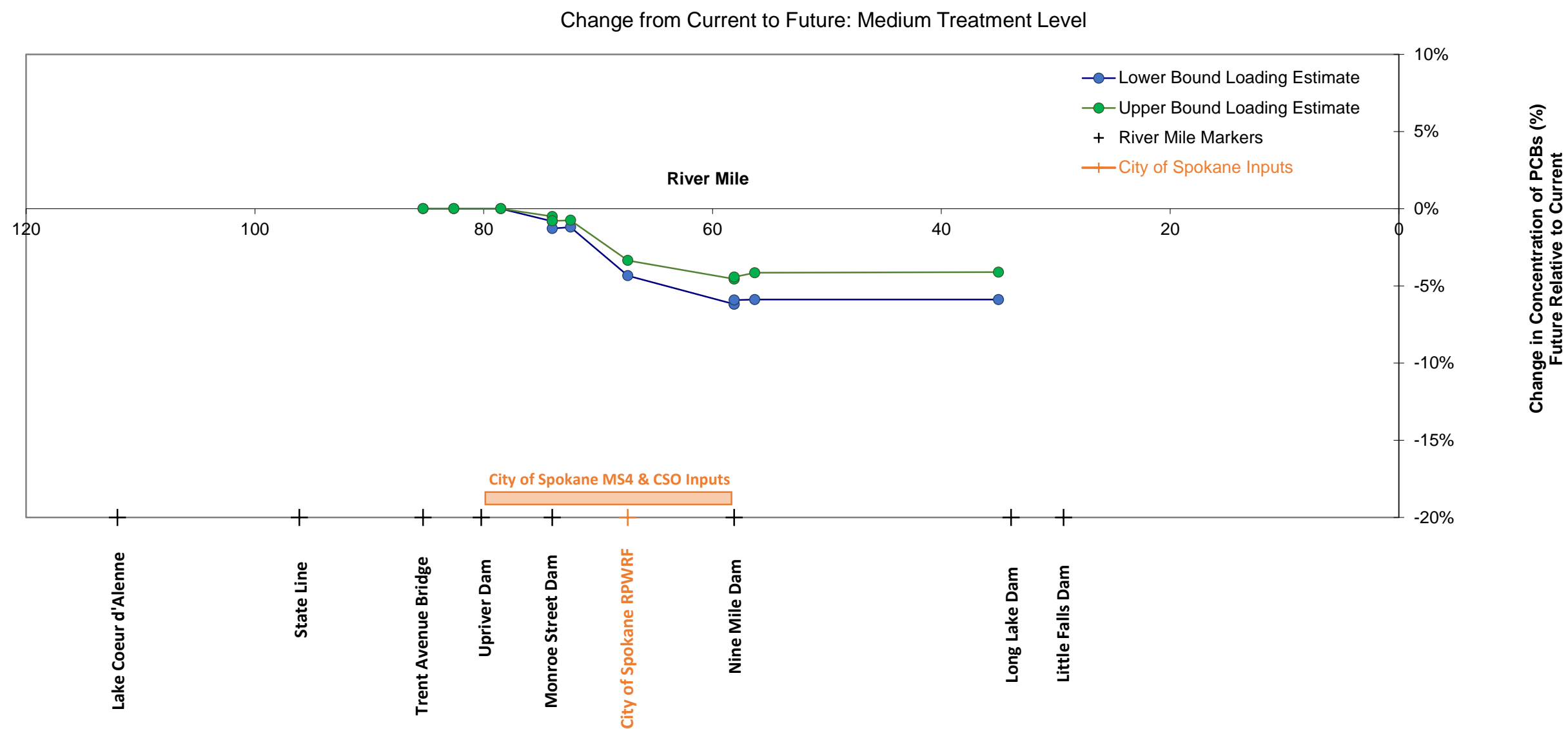


Figure 12: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2018 levels as a function of river mile in response to an intermediary level of treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the blue and green lines.

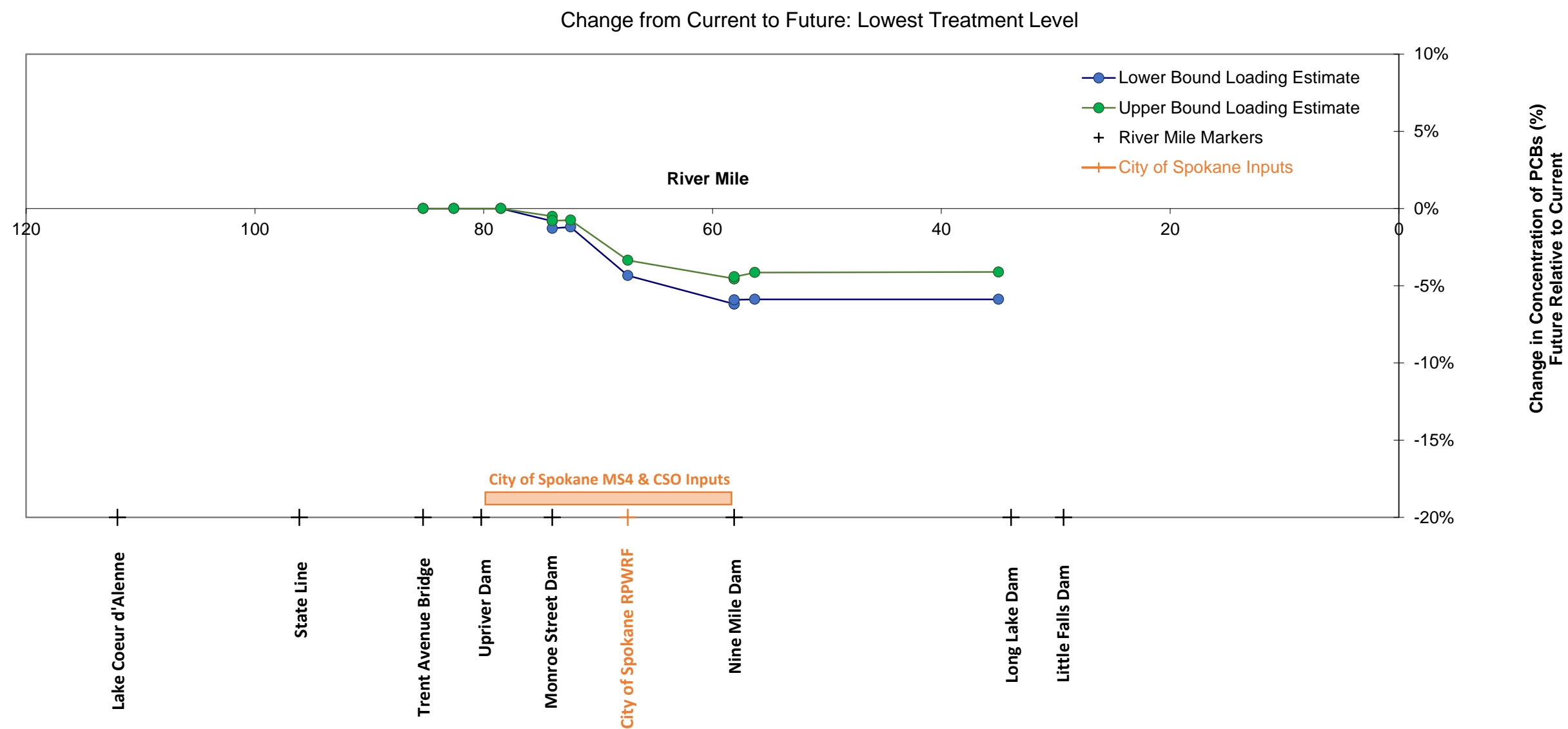


Figure 13: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2018 levels as a function of river mile in response to minimum treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the green and the blue lines.

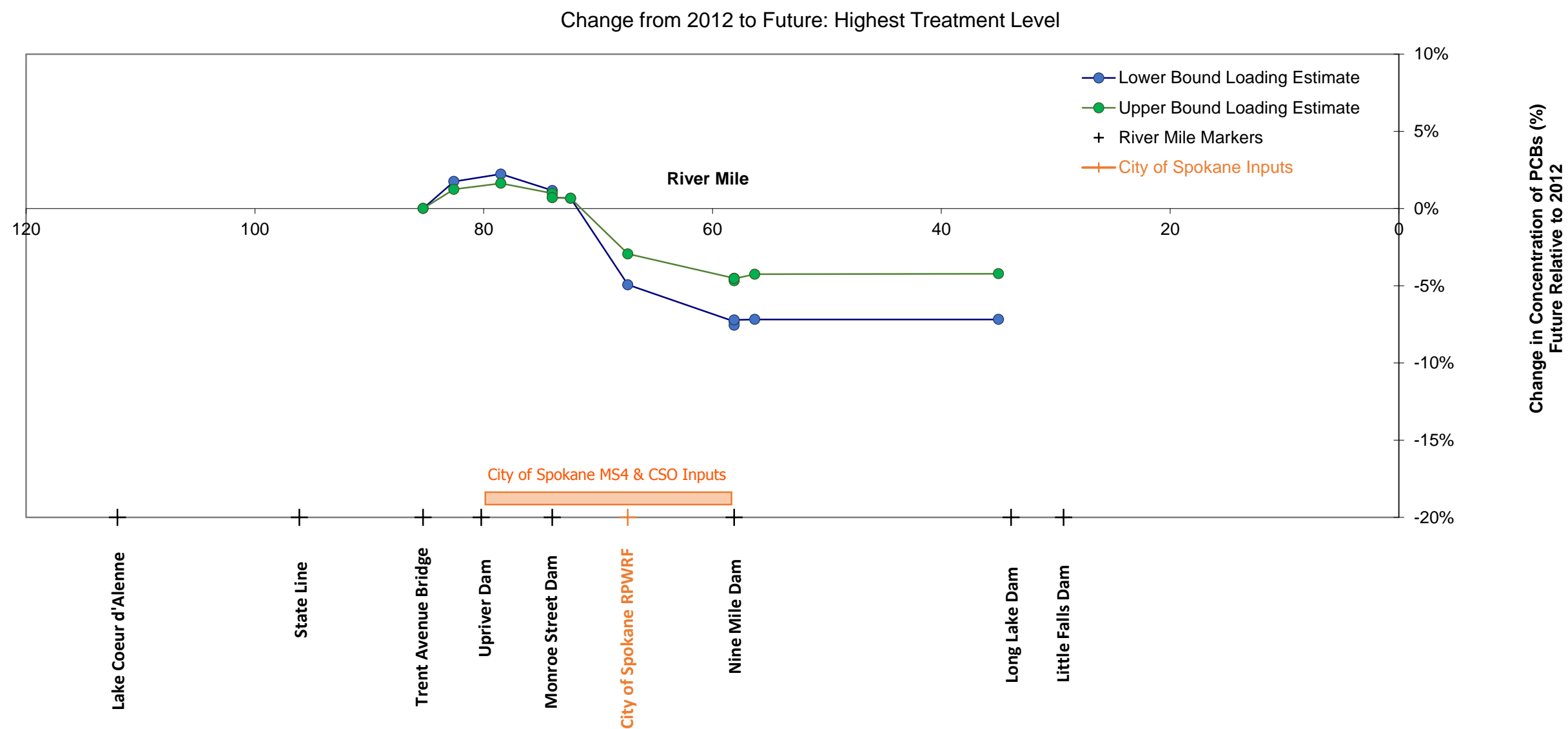


Figure 14: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2012 levels as a function of river mile in response to maximum treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the green and the blue lines.

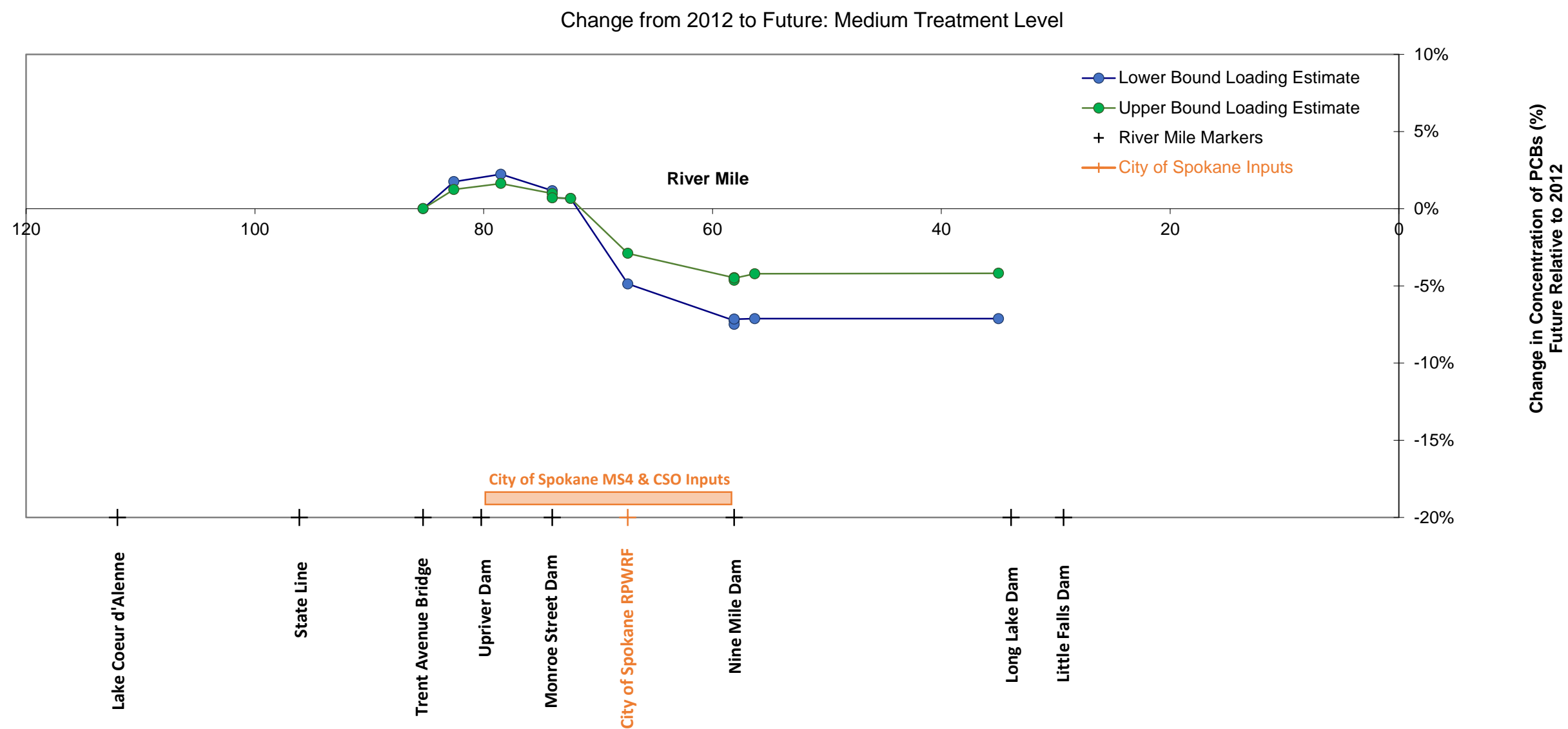


Figure 15: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2012 levels as a function of river mile in response to an intermediary level of treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the green and the blue lines.

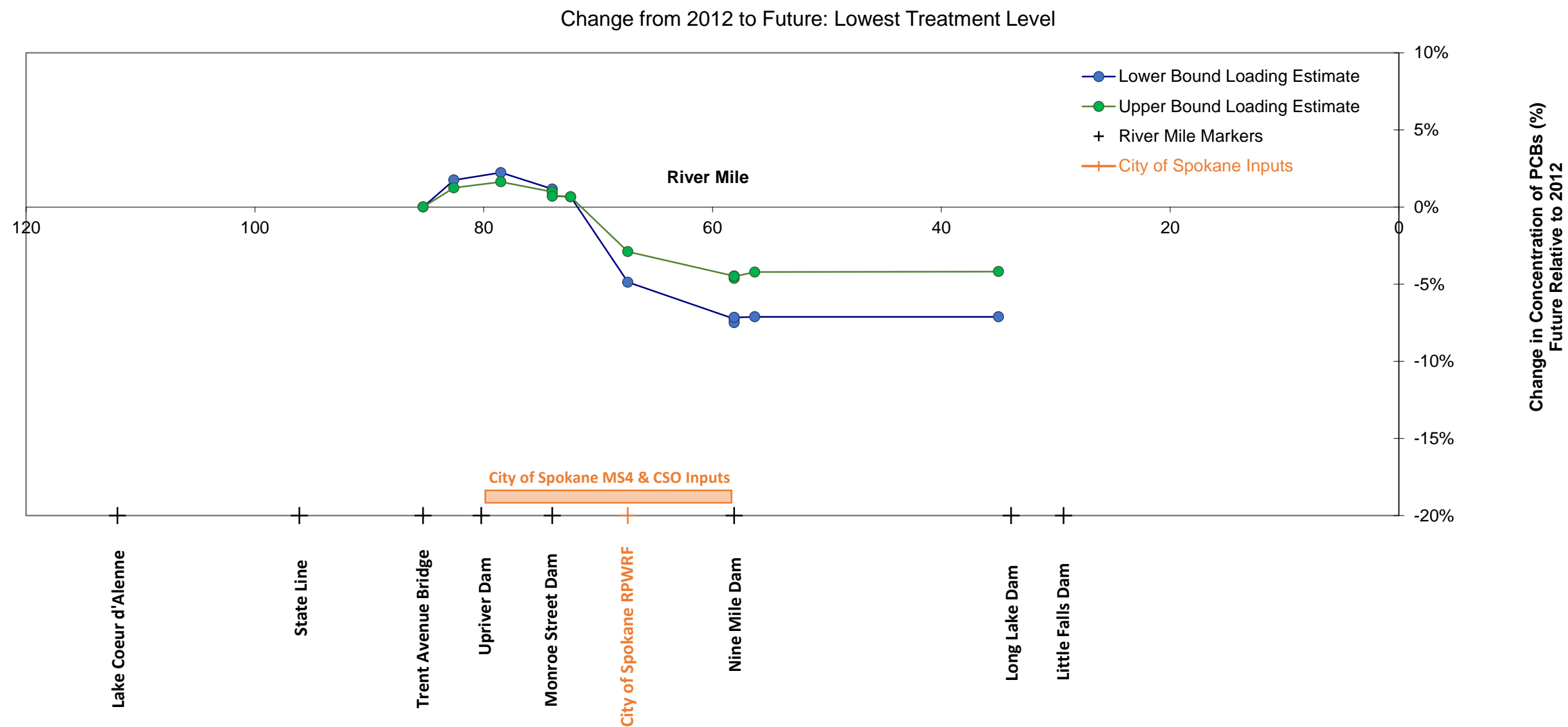


Figure 16: Expected changes (%) in concentrations of PCBs in water, sediment and fish of the Spokane River from 2012 levels as a function of river mile in response to minimum treatment at the City of Spokane facilities. The blue line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to zero for determination of PCB loadings. The green line assumes that non-detected concentrations of PCB congeners or Aroclors in water are equal to the detection limit for determination of PCB loadings. Actual changes in concentrations are expected to fall in between the green and the blue lines.

6.3.2. Compilation and Analysis of Concentrations of PCBs in Water, Sediments and Fish of the Spokane River

This section presents the compilation and analysis of concentrations of PCBs in water, sediments and fish of the Spokane River for the period of 1990 and 2018, for which measurements are available. The analysis explores whether there are apparent differences in concentrations of PCBs in media of the Spokane River between earlier (i.e. before 2007) and more recent (i.e. since 2012) time periods.

6.3.2.1 Surface Water

Information on the concentrations of PCBs in surface water from the Spokane River was compiled from several sources which are summarized in **Attachment C**. In the great majority of studies (i.e. nine out of ten studies), concentrations of PCBs in water were expressed in terms of the total concentration of PCB congeners, which is the concentration derived by adding up the concentrations of all measured PCB congeners. Only one study reported measured concentrations of PCBs in terms of the sum of Aroclors. Concentrations expressed in terms of the sum of Aroclors were compared to concentrations expressed in terms of the sum of PCB congeners without any conversion. The rationale for doing this is that when the same samples were analyzed using the two different methods for analysis, concentrations of PCBs expressed in terms of the sum of Aroclors were so close to the concentrations expressed in terms of the total concentration of PCB congeners that a conversion was not considered meaningful given the magnitude of other areas of uncertainty in the data. While this comparative analysis involved fish samples instead of water samples, there is no reason to assume that the near equality of concentrations based on sum of Aroclors and PCB congeners would be significantly different between the sample types.

One of the difficulties of analyzing PCB congeners in river water is that the concentrations of individual congeners are often very low. This makes them very hard to detect with analytical instruments. This difficulty was also encountered in the analysis of water samples from the Spokane River. In many of the water samples from the Spokane River, concentrations of most of the PCB congeners that were included in the analysis were reported to be below the detection limit¹⁰. In some water samples, not a single PCB congener could be detected above the detection limit. The water sample with the highest fraction of detected PCB congeners

¹⁰ For the total PCB concentrations in water, this also includes congeners that were less than 3x the method blank (see **Footnote 7**).

was collected Above Nine Mile Dam in 2014. In this sample, approximately 68% of the congeners investigated were detected at concentrations above the detection limit and 32% of the congeners were below the detection limit. A higher fraction of detected PCBs congeners in a water sample does not necessarily mean that the concentration of total PCBs in water is greater than that in a sample with a lower reported fraction of detected PCB congeners. This is because detection limits can vary greatly between labs and even between different analyses as a result of the operating conditions of the analytical instruments used to analyze the water sample and the quality of analysis process.

Because a considerable number of PCB congeners in water samples were below the detection limit, it is not possible to state precisely the concentration of the PCBs (i.e. all the congeners combined) in the water samples. However, it is possible to determine the range between the minimum and maximum concentration of PCBs in water. The minimum concentration of PCBs in the water can be determined by assuming that the concentrations of non-detected PCB congeners (or Aroclors) were absent altogether (i.e. concentration of zero). The maximum concentration of PCB in the water can be found by assuming that the concentrations of non-detected PCB congeners (or Aroclors) were equal to the detection limit. The resulting range of concentrations is where the actual concentration of PCBs can be expected to be. The midpoint of this range is equivalent to using half the detection limit for undetected PCB congeners or Aroclors. If few congeners or Aroclors are detected and/or detection limits for PCB congeners or Aroclors are high, then the range of possible concentrations of PCBs can be large. However, if the great majority of congeners or Aroclors are detected and/or detection limits for PCB congeners or Aroclors are low, then the range of possible concentrations of PCBs is small and the concentrations can be determined with greater precision than if the less congeners or Aroclors are detected.

Attachment C provides several statistics to summarize the concentrations of total PCBs in water samples from the Spokane River. In cases where multiple samples were collected, the PCB concentrations reported in this section represent averages (i.e. arithmetic means) of all samples collected within the same year and from the same section of the Spokane River.

Attachment C illustrates that the earliest reported information on concentrations of PCBs in water were studies by Ecology dating back to 2000 (Golding 2001) and 2003 (Serdar et al. 2011). Concentration data were measured on a regular basis only from 2012-2018. Much of the recent data (2014-2018) were collected by LimnoTech on behalf of SRRTTF (LimnoTech 2015, LimnoTech 2016a, LimnoTech 2016b, LimnoTech 2017, LimnoTech 2019, PGG 2019b) and by Ecology (Era-Miller 2014a, Era-Miller and McCall 2017, Hobbs et al. 2019).

Figure 17 illustrates the concentrations of PCBs in water of the Spokane River as a function of year. Different river sections are shown in different panels. The data points on the plot correspond to arithmetic averages calculated using half the detection limit for non-detected congeners/Aroclors, and the error bars correspond to averages calculated using the detection limit (upper bar) or zero (lower bar) for non-detected congeners/Aroclors. **Figure 17** shows that for all sections of the River, both upstream and downstream of the City of Spokane sources, concentrations of PCBs in water decreased since 2000-2003 and between 2012 and 2018. The greatest declines appear to have taken place in the upper sections of the Spokane River. The smallest declines in the concentrations of PCBs in water occurred in the lower sections of the river (e.g. RM 58.1-33.9, Above Nine Mile).

It can, therefore, be concluded that concentrations of PCBs in water of all sections of the Spokane River have declined since 2000-2003, and between 2012 and 2018. Declines in the concentration of PCB in water are likely due to significant reductions in PCB discharges between 2000-2003 and 2018. Upgrades at the City of Spokane facilities, as well as other remediation in the River such as capping of historic sediment contamination near Upriver Dam/Donkey Island (near RM 80 to 84), likely have contributed significantly to the reduction in PCB discharges over the 2000-2003 to 2018 time period.

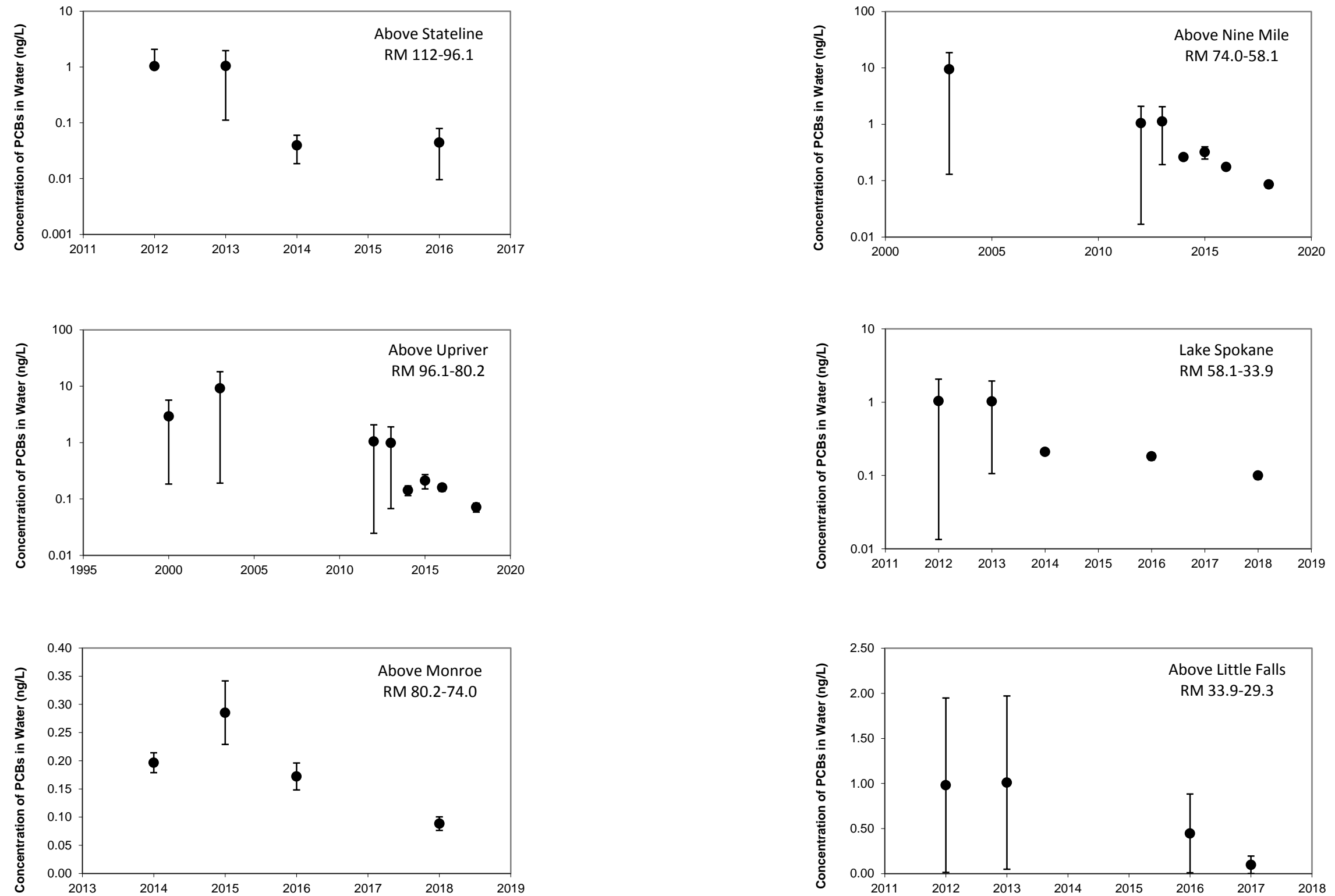


Figure 17: Concentrations of PCBs in water (ng/L) of various sections of the Spokane River (expressed in terms of river miles), as a function of the year of water sample collection. The error bars represent the range of concentrations that include the actual concentrations.

6.3.2.2 Sediments

Attachment C summarizes the compilation of the concentrations of PCBs in sediments of the Spokane River. As described in **Sections 5.1.3** and **5.3**, with the exception of Lake Spokane and Upriver Dam, much of the Spokane River bottom consists of gravel, cobbles and boulders. As a result, long-term monitoring of PCB concentrations in sediments is limited by a paucity of sediment and sampling is restricted to areas where sediment is present. There are also few PCB sediment studies from recent years (2013-2018). In total, 12 reports documented concentrations of PCBs in sediments of the Spokane River. Seven of the 12 studies reported concentrations of PCBs in sediment in terms of the Aroclors and the remaining five studies reported concentrations of PCBs that were determined by adding up the concentrations of all measured PCB congeners. The use of different methods of measuring and reporting PCB concentrations introduces some uncertainty in the analysis of the available PCB concentrations. However, as discussed above for water samples, fish samples analyzed by the two methods of analysis tend to produce similar results. Hence, all reported PCB concentrations in sediment were used in the same analysis without manipulation of the data.

Since sediment analyses also encountered non-detected PCB congeners and Aroclors, ranges of concentrations of total PCBs in river sediments are reported. As for the concentrations of PCBs in water, a range of total PCBs was determined, within which the actual concentration of total PCBs is expected to be. The minimum was determined by assuming that the concentrations of non-detected PCB congeners (or Aroclors) were zero. The maximum was determined by assuming that the concentrations of non-detected PCB congeners (or Aroclors) are equal to the detection limit. These concentration ranges were determined as arithmetic averages of all samples collected within the same year and from the same section of the Spokane River. The mid-range sample point shown on the figures corresponds to using one-half the detection limit for the non-detected congeners.

Figure 18 illustrates temporal profiles of the concentrations of PCBs in sediments from different parts of the Spokane River between 1990 and 2018. It shows that concentrations of PCBs in sediments between RM 96.1 and 80.2 (i.e. Above Upriver, upstream of the City of Spokane facilities) fell, initially very rapidly between 1993 and 1994, and after that more slowly to concentrations of 1 to 2 mg/kg organic carbon in 2018. Immediately downstream of this location, between RM 80.2 and 74.0, (i.e. Above Monroe, upstream of the majority of City of Spokane discharges) concentrations of PCBs in sediments also appear to have dropped between 1993 and 2013, although a concentration measured in 2018 is not consistent with this trend. There are limited data from the 1990s and no data from recent

years from the Above Nine Mile (RM 74.0-58.1) river section, downstream of the City of Spokane facilities. Concentrations of PCBs in sediments of Lake Spokane, Little Falls Pool, and Spokane Arm (RM 58.1 to 0) do not show changes over time and have remained relatively constant at concentrations of 1 to 4 mg/kg organic carbon.

The data compilation indicates that there likely have been significant reductions in the concentration of PCBs in sediments over time in locations upstream of the City of Spokane facilities. However, for locations downstream of the City of Spokane facilities, there are insufficient data to make conclusions about changes in the concentrations of PCBs in sediments that may have occurred as a result of modifications at the City of Spokane facilities. In some locations downstream of the City of Spokane Facilities (e.g. Above Nine Mile), data limitations are a result of minimal sediment in the River.

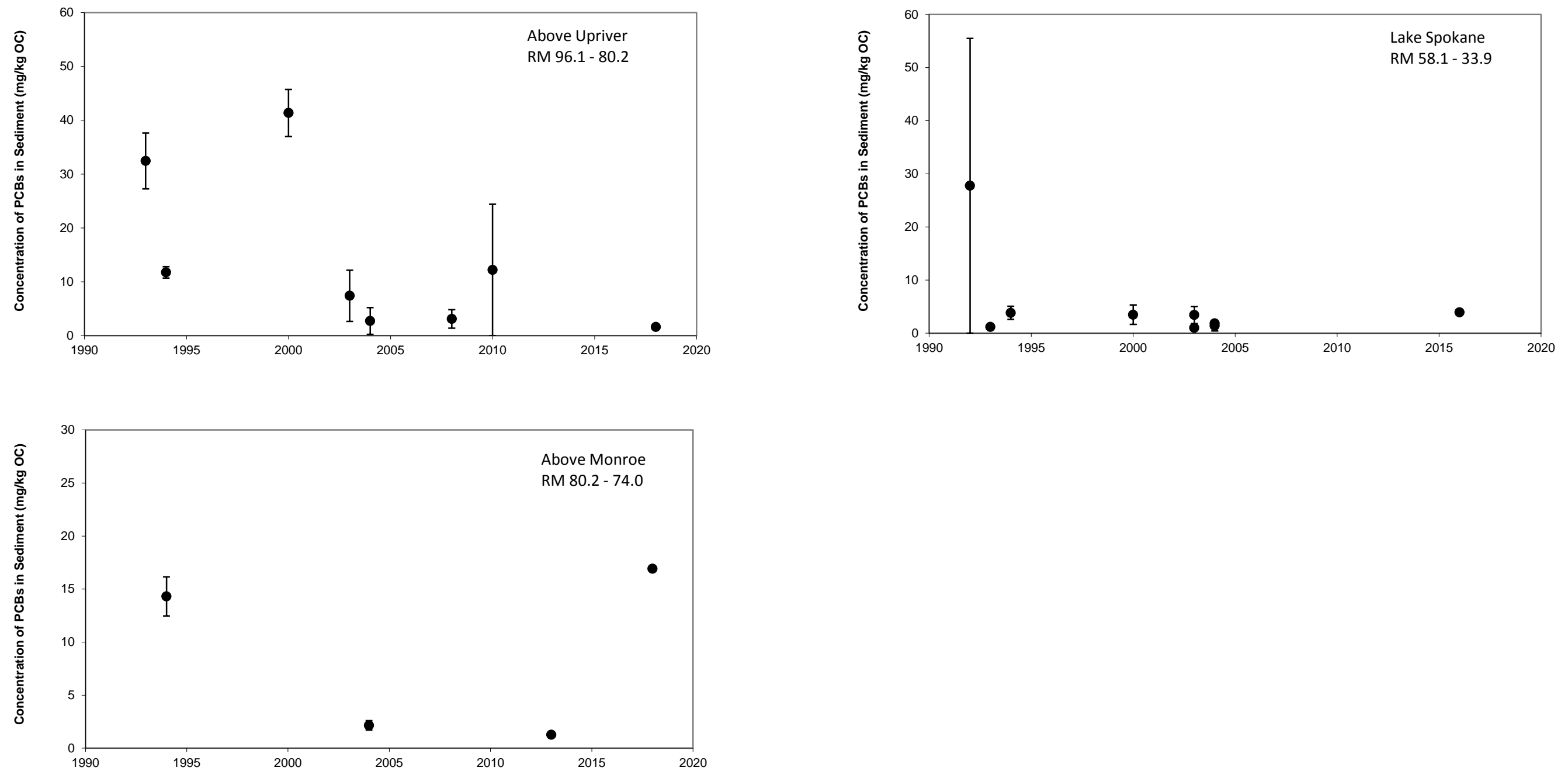


Figure 18: Concentrations of PCBs in sediments (mg/kg OC) of various sections of the Spokane River (expressed in terms of river miles (RM)) as a function of the year of sediment sample collection. The error bars represent the range of concentrations that include the actual concentrations.

6.3.2.3 Fish

Attachment C summarizes the compilation of the concentrations of PCBs in fish of the Spokane River. In total, 13 reports documented concentrations of PCBs in 14 species of fish of the Spokane River. This section focuses on the three fish species that were sampled most frequently in the Spokane River: Largescale Sucker, Rainbow Trout and Mountain Whitefish. PCB concentrations in other fish species from the Spokane River are summarized in **Attachment C**. Concentrations of PCBs in fish are reported both in terms of Aroclors and PCB congeners. A number of fish samples were analyzed by both methods of analysis. The analyses of these fish samples showed that PCB concentrations expressed in terms of the sum of Aroclors are very close to PCB concentrations expressed in terms of the sum of PCB congeners. All reported PCB concentrations were therefore used without manipulation.

As with sediment and water, minimum total PCB concentrations assume that concentrations of non-detected PCB congeners (or Aroclors) were zero, and maximum total PCB concentrations assume non-detected PCB congeners (or Aroclors) are equal to the detection limit. The sample points presented on the figure represent arithmetic average concentrations of PCBs in fish on a lipid normalized basis, and assigning half the detection limit to non-detected congeners/Aroclors. Because concentrations of PCBs in fish are generally high, the impact of non-detected concentrations on the sum concentration of all PCB congeners or all Aroclors is relatively low. The range between minimum and maximum concentrations is therefore small in most cases.

Figure 19 (Largescale Sucker) **Figure 20** (Rainbow Trout) and **Figure 21** (Mountain Whitefish) illustrate that among the three fish species for which most data are available, concentrations of PCBs in Largescale Suckers were generally the highest and higher than those in Rainbow Trout. Concentrations of PCBs in Mountain Whitefish were the lowest. These observations indicate that there are substantial species-specific differences in the PCB concentrations among fish species in the Spokane River. These differences are likely related to differences in fish behavior, including dietary and habitat preferences. This indicates that it is important to investigate temporal changes in PCB concentrations on a species-specific basis.

Figure 19 to **Figure 21** also illustrate that in certain sections of the River, concentrations of PCBs in fish have declined over time. For example, **Figure 19** illustrates that concentrations of PCBs in Largescale Suckers declined in sections of the River both above and below City of Spokane's sources (i.e. between RM 96.1-80.2, 74.0-58.1 and 58.1-33.9). **Figure 20** illustrates that concentrations of PCBs in Rainbow Trout also declined between RM 96.1-80.2 and 74.0-58.1, but not in the intermediary reach. Concentrations of PCBs in Mountain Whitefish declined in two sections of the River receiving PCB inputs from the City of Spokane, but not

farther downstream in Lake Spokane (**Figure 21**). These results are supported by a temporal trends analysis that detected statistically significant declines in concentrations of PCBs in fish tissues over time (since the 1990s) and specifically between 2005 and 2012 in the species and river sections described above (**Attachment C**).

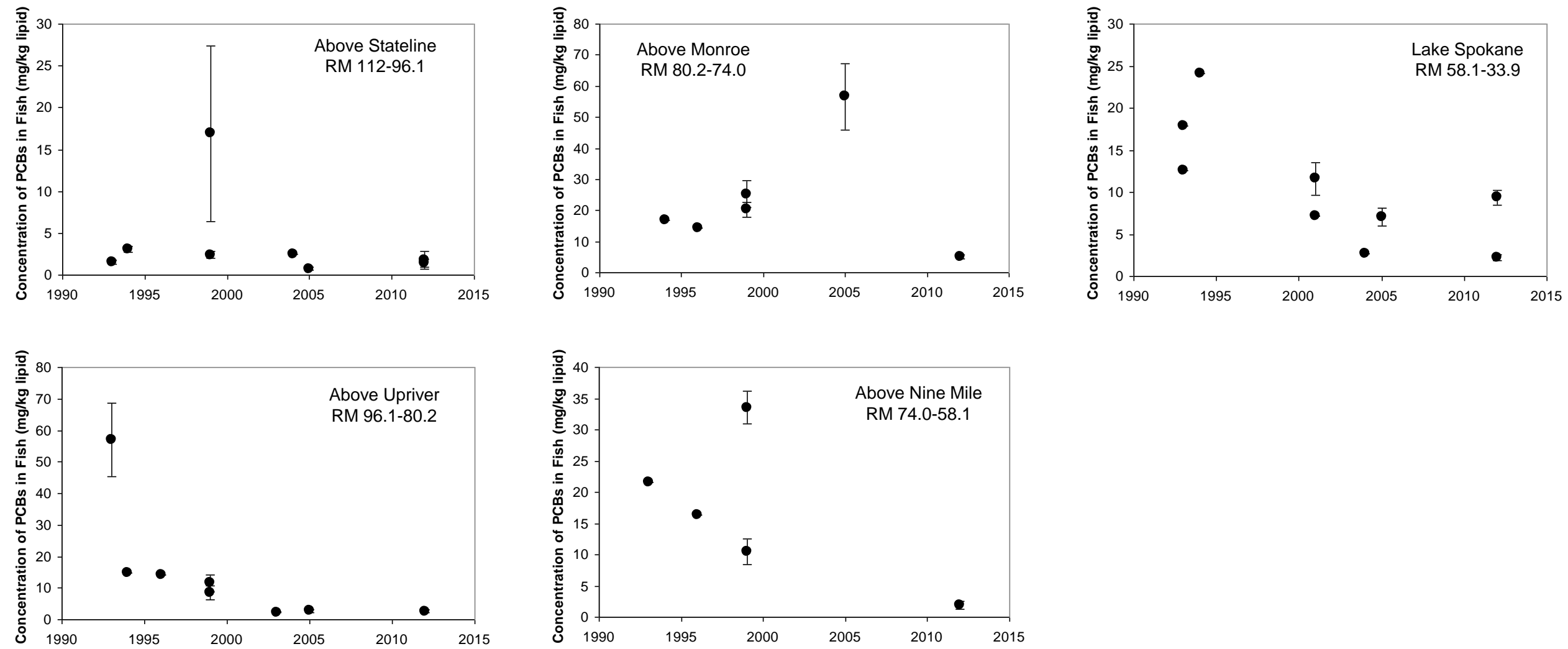


Figure 19: Concentrations of PCBs in Largemouth Sucker (mg/kg lipid) in reaches of the Spokane River over time (1992-2012).

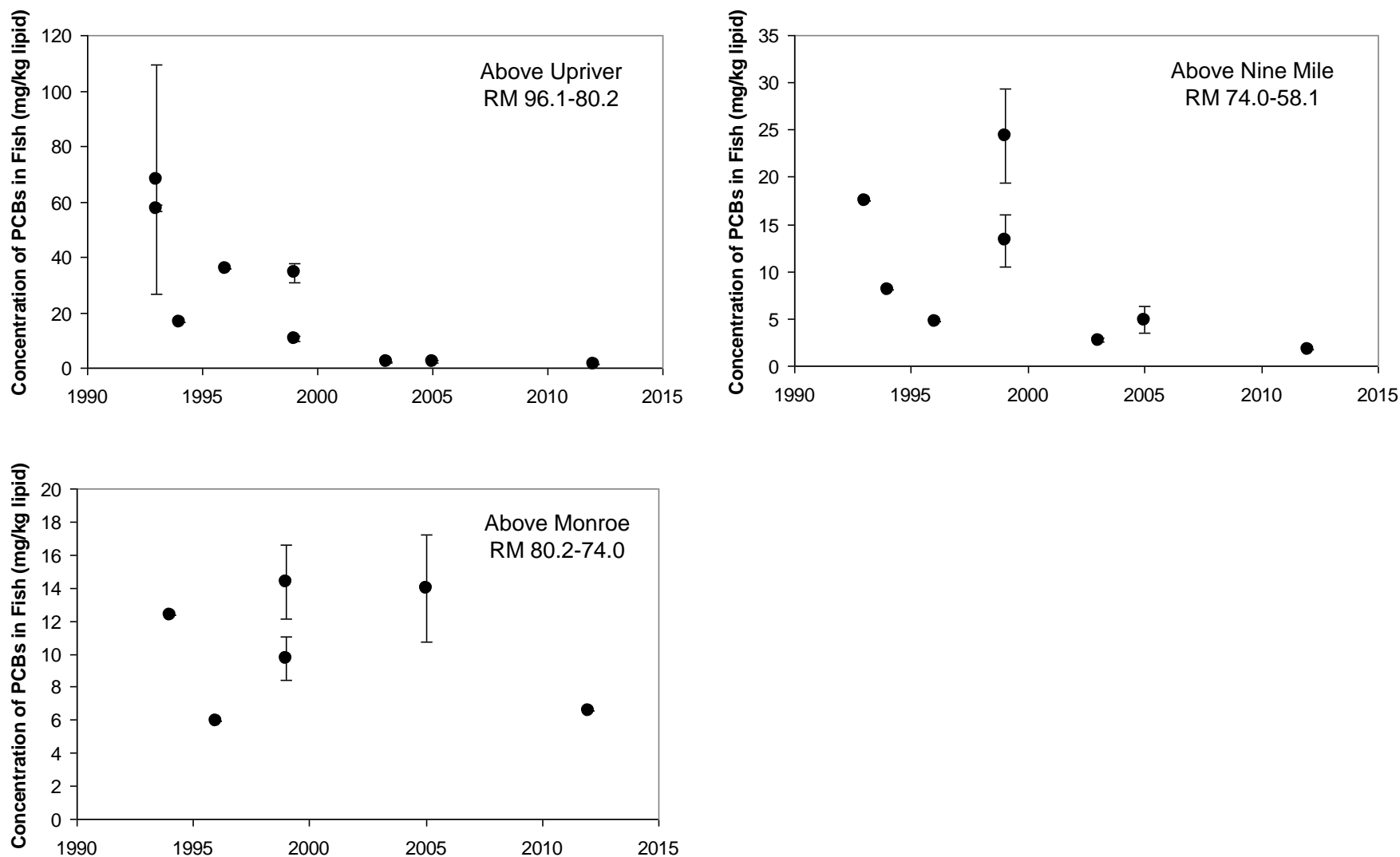


Figure 20: Concentrations of PCBs in Rainbow Trout (mg/kg lipid) in reaches of the Spokane River over time (1992-2012).

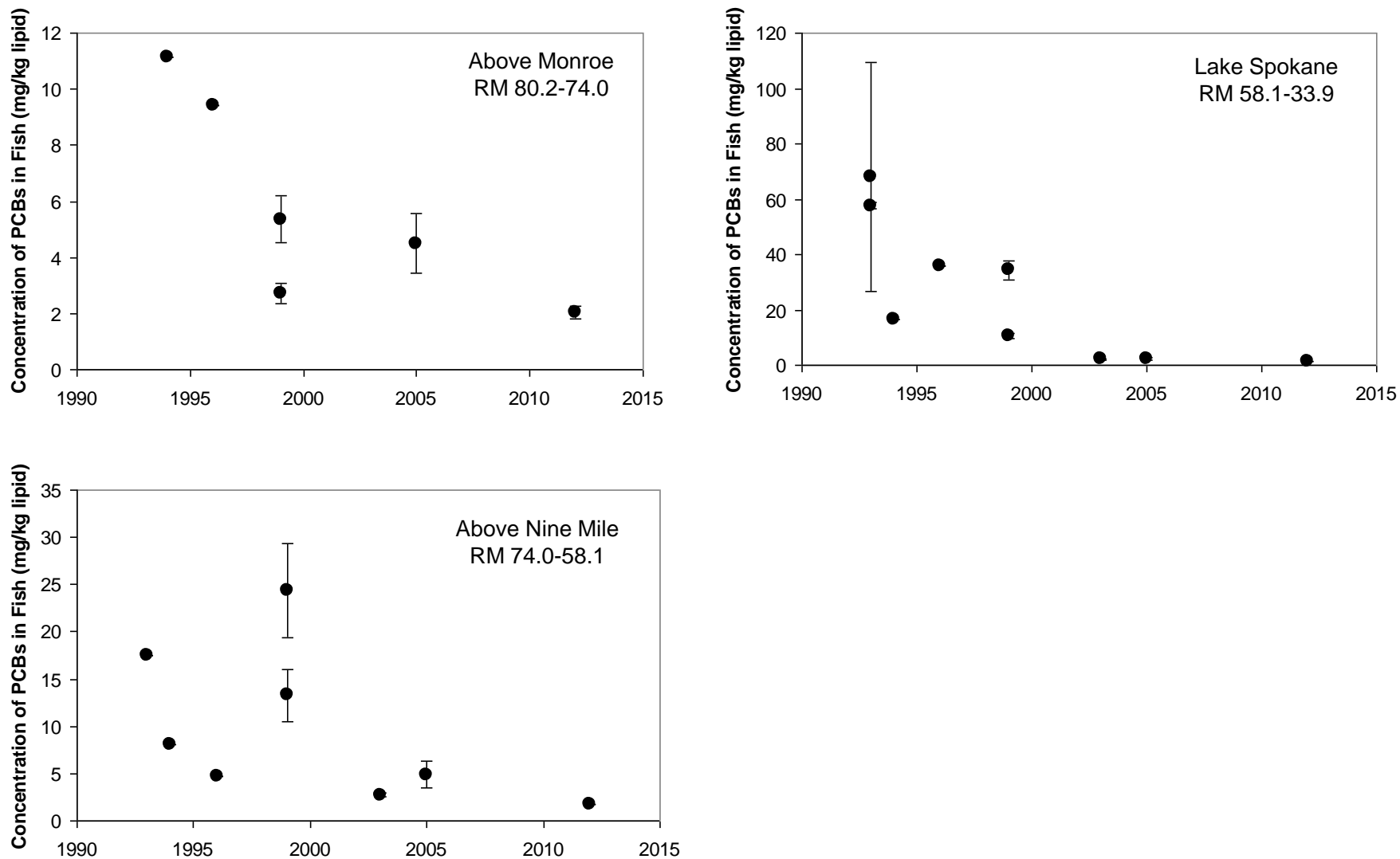


Figure 21: Concentrations of PCBs in Mountain Whitefish (mg/kg lipid) in reaches of the Spokane River over time (1992-2012).

6.3.3. Assessment of Future Predicted Concentrations of PCBs in Water, Sediment and Fish of the Spokane River as a Result of Treatment of the City of Spokane Facilities

Using the compilation of existing measured concentrations of PCBs in water, sediments and fish of the Spokane River, and the changes in PCB discharges to the River between time periods or following treatment by the City of Spokane, it is possible to calculate the concentrations of PCBs that can be expected in water, sediment and fish in various sections of the Spokane River over time. Three assessments were conducted:

- i. Due to a lack of recent fish data, current (2018) concentrations in fish were calculated from 2012 fish data based on changes in PCB loadings that occurred between the intermediary (2012) and current time periods. Results from two scenarios calculating PCB concentrations in fish are presented below (see **Section 6.2.1.** for scenario descriptions).
- ii. Future (2030) concentrations in water, sediment and fish were calculated based on anticipated PCB loadings reductions after further remedial treatment of the City of Spokane facilities/systems. Six future loadings reductions scenarios were evaluated in **Section 6.2.1.** For simplicity, results of the minimum and maximum scenarios are reported in this section. Because predicted future loadings from the City of Spokane under low, medium and high treatment levels were very similar, the predicted concentrations resulting from different treatment scenarios are similar, with most of the variation due to using either the lower or upper bounds of the PCB loadings estimates for non-City of Spokane sources.
- iii. A third hypothetical scenario was used to predict PCB concentrations in fish in 2018 and 2030, under the assumption that the City of Spokane did not reduce PCB discharges to the River after 2012. Predicted PCB concentrations resulting from this scenario are not discussed in detail but are provided in **Attachment C.** Under this “no further treatment” condition, concentrations of PCBs in fish would be expected to increase after 2012 in all sections of the River (RM 80.2 to 29.3) and predicted concentrations in 2018 and 2030 are higher than those predicted for these time periods under the status quo treatment by the City of Spokane (i.e. assessments i and ii above).

Data reported in this section are geometric mean concentrations of total PCBs using the half detection limit for non-detected congeners/Aroclors. Error bars on the plots represent variability in concentrations of PCBs measured in multiple samples and are equivalent to one standard deviation of above and below the geometric mean.

Future concentrations of PCBs that can be expected in water are shown along with measured baseline and current concentrations of PCBs in **Figure 22**. **Figure 22** shows that current (2016-2018) concentrations fell substantially below baseline (2000-2003) concentrations and that future concentrations are expected to be even lower. Treatment at the City of Spokane facilities will reduce the concentrations of PCBs in water downstream of the City of Spokane facilities. The greatest reduction in the concentration of PCBs in water, of approximately 6.0%, is expected for the section of the River between RM 74.0-58.1 (Above Nine Mile) in response to the highest level of treatment, and assuming the lower bound of PCB loads for non-City of Spokane sources. The minimum reduction in concentrations of PCBs in water expected in RM 74.0-58.1 between 2018 and 2030 is 4.4% and results from the lower level of treatment and assuming the upper bound of PCB loads for non-City of Spokane sources. Future predicted concentrations of PCBs in water in this river section range from 80.3 to 81.6 pg/L. Concentrations of PCBs in Lake Spokane are expected to be 4.1 to 5.9% lower in the future than in 2018 and range between 92.5 and 94.3 pg/L. No reduction in concentration is expected for upstream sections of the River unaffected by remediation initiatives at the City of Spokane and concentrations of PCBs are predicted to remain unchanged in sections above RM 80.2.

Baseline, current and future predicted concentrations of PCBs in sediment, normalized to organic carbon, of the Spokane River are presented in **Figure 23**. **Figure 23** illustrates that concentrations of PCBs in sediments downstream of the City of Spokane facilities are also expected to decline in the future as a result of treatment at the City of Spokane facilities. The Above Nine Mile river stretch (RM 74.0 to 58.1) is not shown due to a lack of sediment in this section of the river. In Lake Spokane (RM 58.1-33.9) and Little Falls Pool (RM 33.9-29.3), the maximum reduction in the concentration of PCBs in sediment relative to current levels that is expected to be achieved over time in response to highest level of treatment, and assuming the lower bound of PCB loading estimates for non-City of Spokane sources, is approximately 5.9%. A minimum reduction of 4.1% is expected to result from the lower level of treatment and assuming the upper bound of PCB loading estimates for non-City of Spokane sources. These future predicted concentrations of PCBs in sediment equal 3.68 to 3.75 mg/kg organic carbon in Lake Spokane and 0.79 to 0.85 mg/kg organic carbon in Little Falls Pool. No reduction in concentration of PCBs is expected for sections of the River unaffected by remediation initiatives at the City of Spokane.

Along with measured baseline and 2012 concentrations of PCBs in fish, **Figure 24** illustrates the predictions of 2018 (current) and future concentrations of PCBs in Largescale Sucker, Rainbow Trout and Mountain Whitefish. These fish species are shown because they have the most concentration data available in different sections of the River and from different time

periods. Predicted concentrations of PCBs in other fish species (e.g. Common Carp, Brown Trout, Northern Pike/minnow and Yellow Perch) are presented in **Attachment C** and these fish are expected to undergo similar changes in concentrations as a result of treatment.

Figure 24 shows that in all three fish species, concentrations of PCBs in sections of the River upstream of the City of Spokane facilities (above RM 80.2) are not expected to undergo changes as a result of emission reduction initiatives at the City of Spokane facilities. This is because reductions in PCBs inputs at the City of Spokane facilities only affect downstream sections of the Spokane River. Concentrations of PCBs in fish above RM 80.2 are expected to remain the same as levels measured in 2012. This prediction does not include analysis of upstream migration of fish from sections of the River downstream of the City of Spokane facilities to sections upstream of the City of Spokane facilities. Fish genetic and tracking studies suggest that this type of fish movement is not prevalent in the Spokane River.

In the Above Nine Mile river stretch (RM 80.2 to 74.0) there is an increase in concentration predicted between 2012 and 2018 (1.5 to 2.0%) and between 2012 to future (approximately 0.7%) for all scenarios modelled. This is due to increases in PCB loadings from sources upstream of the City of Spokane between the 2012 and 2018 time periods (see **Section 6.3.1.4**). In sections of the River downstream of the City of Spokane facilities (RM 74.0-58.1, RM 58.1-33.9, and RM 33.9-29.3), concentrations of PCBs in fish are expected to have declined between 2012 and 2018 and are predicted to decline further in the future, as a result of loading reductions by the City of Spokane. The reduction in concentrations of PCBs in fish is expected to be greatest in RM 74.0-58.1 (i.e. 0.08 to 1.3% reduction between 2012 and 2018, and 4.5 to 7.2% lower between 2012 and future), and slightly lower between RM 58.1 and 29.3.

In the section of the River immediately downstream of the City of Spokane facilities (i.e. Above Nine Mile; RM 74.0-58.1), concentrations of PCBs in Largescale Suckers are predicted to fall from 0.0512 mg/kg ww in 2012 to 0.0506 to 0.0512 mg/kg ww in 2018 and further to between 0.0475 to 0.0489 mg/kg ww for all levels of treatment/scenarios in the future. In Lake Spokane, between RM 58.1 to 33.9, concentrations of PCBs in Largescale Suckers are expected to approach concentrations of 0.202 to 0.204 mg/kg ww in 2018 and between 0.190 and 0.196 mg/kg ww in response to future treatment by the City of Spokane. The reason PCB concentrations in Lake Spokane are predicted to be higher than those in the Above Nine Mile section is because higher concentrations of PCBs were observed in Largescale Suckers in Lake Spokane than in the Above Nine Mile section in 2012. Concentrations of PCBs in Largescale Suckers of Lake Spokane have declined from 0.309 mg/kg measured in the baseline period.

Concentrations of PCBs in Rainbow Trout in the section of the River just downstream of the City of Spokane facilities (i.e. RM 74.0-58.1), are expected to reach concentrations of 0.0418-0.0423 mg/kg ww in 2018 and 0.0393-0.0404 mg/kg ww in the future under both high and low treatment scenarios. In Mountain Whitefish, concentrations of PCBs in sections of the River downstream of the City of Spokane facilities (i.e. RM 74.0-58.1), are expected to attain concentrations of 0.206-0.208 mg/kg ww in 2018 and 0.193-0.199 mg/kg ww as a result of both the highest and lowest levels of treatment.

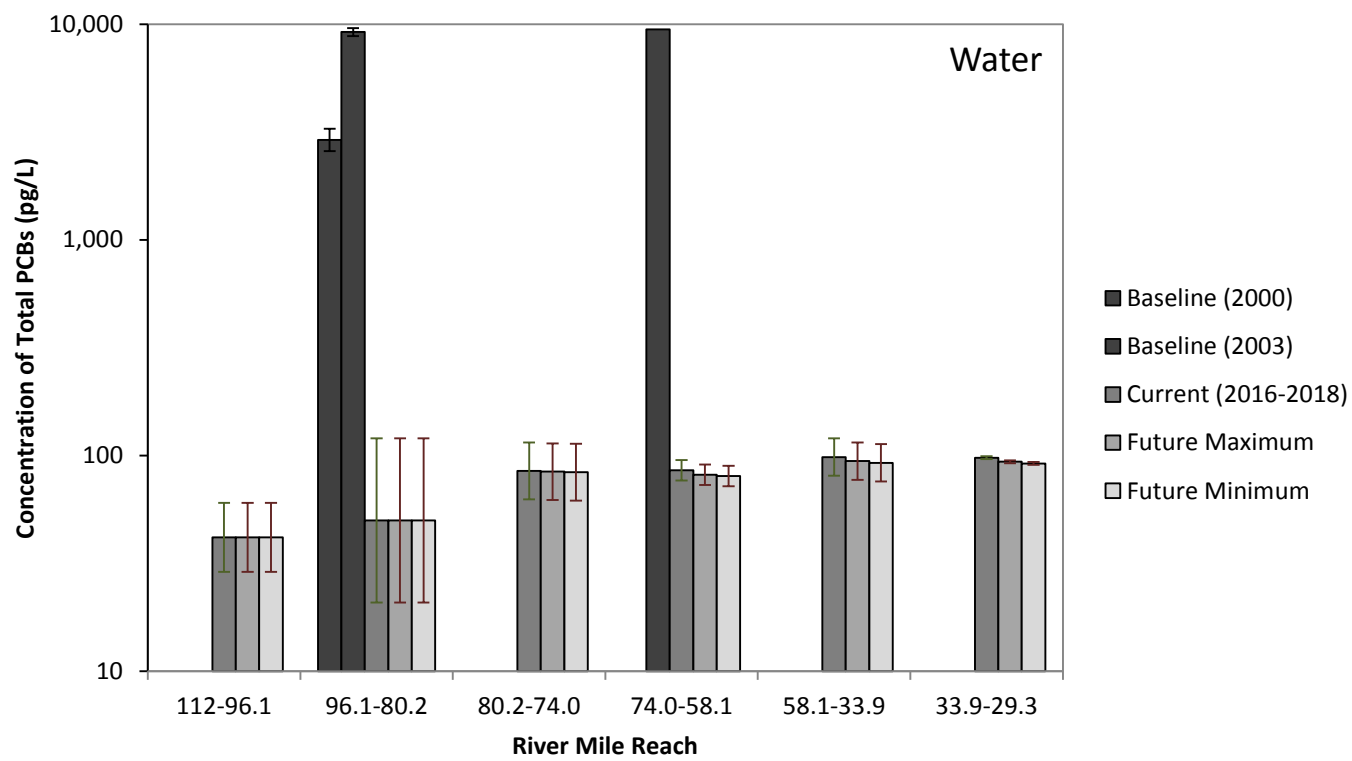


Figure 22: Predicted future (2030) concentrations of PCBs in surface water (ng/L) in reaches of the Spokane River.

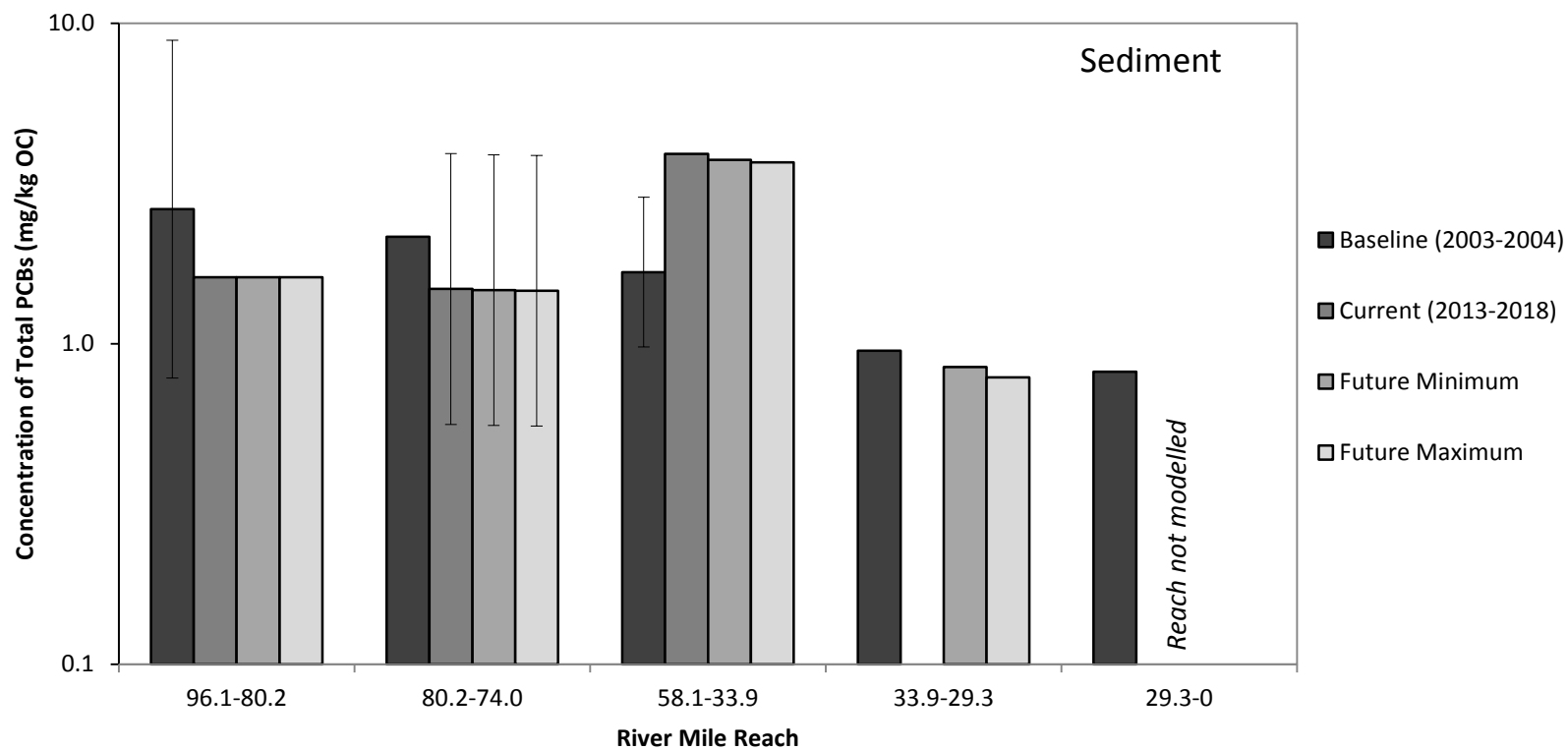


Figure 23: Predicted future (2030) concentrations of PCBs in sediment (mg/kg OC) in reaches of the Spokane River.

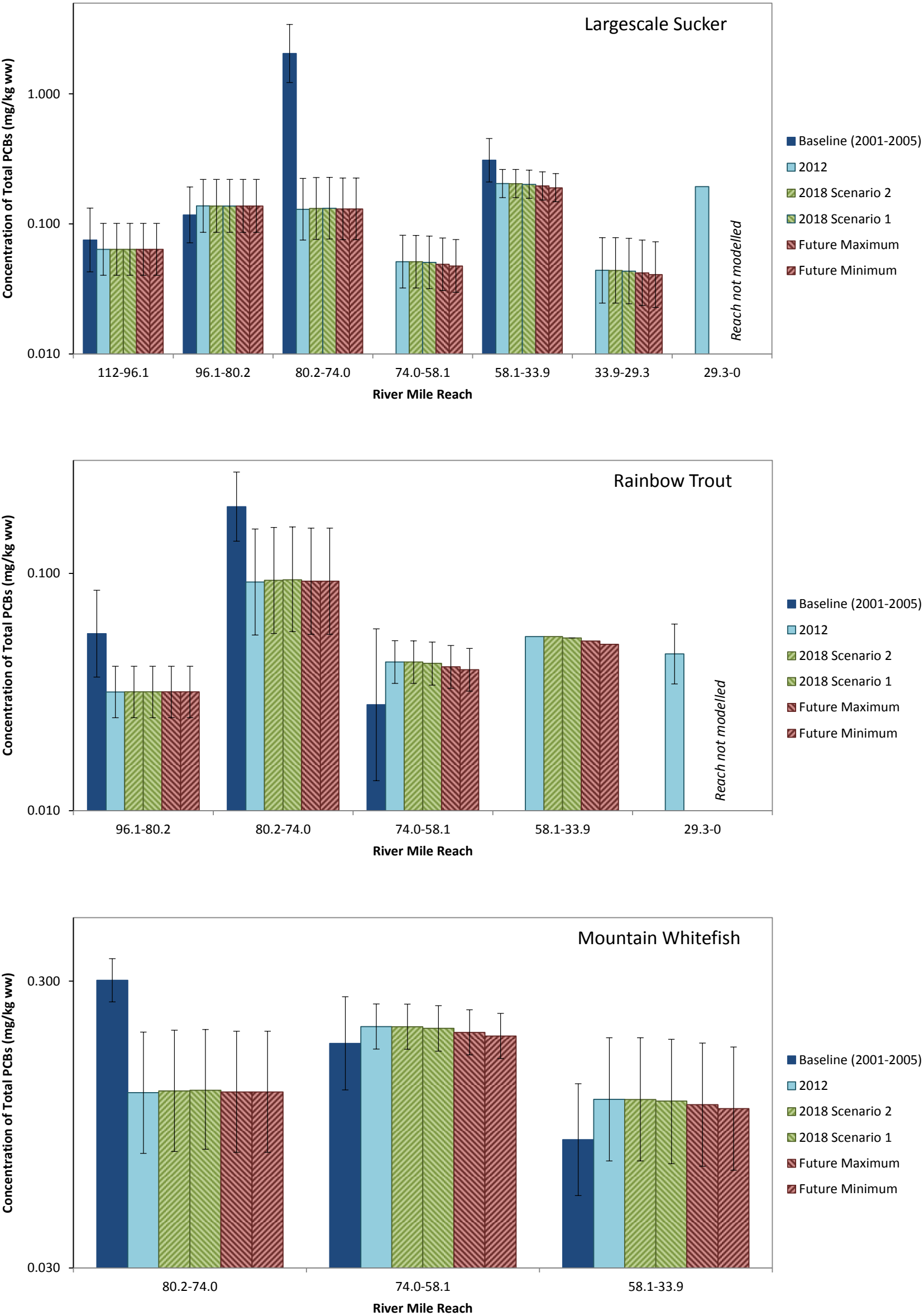


Figure 24: Baseline, 2012 and predicted current (2018) and future (2030) concentrations of PCBs (mg/kg ww) in fish species in reaches of the Spokane River.

6.4. Conclusions

Since the 2003-2007 time period, the City of Spokane has reduced discharges of PCBs from its facilities to the Spokane River by 65 to 68%, i.e. a reduction in PCB discharges by a factor of 2.8 to 3.2. These reductions in PCB discharge are expected to have contributed to a reduction in the concentrations of PCBs in water, sediments and fish species by approximately 7.1 to 12.1% in sections of the River downstream of the City of Spokane facilities. Reductions in the concentrations of PCBs in water and several fish species, over the period of approximately 2000 to 2018 have indeed been observed in sections of the Spokane River both upstream and downstream of the City of Spokane facilities. The empirical concentration data indicate that PCB discharge reduction efforts at the City of Spokane facilities as well as at other locations in the River (e.g. near Upriver Dam/Donkey Island [RM 80 to 84] where River sediments were capped) have caused a significant reduction in the concentrations of PCBs in fish of the Spokane River.

Further planned reductions of PCB discharges by the City of Spokane will drastically reduce the discharges of PCBs by the City of Spokane to levels where the City of Spokane contributes only 1.2 to 2.0% of the total known PCB inputs into the Spokane River. Relative to the current time period, the planned remedial efforts at the City of Spokane facilities are expected to reduce concentrations of PCBs in water, sediments and fish over time by 4.2 to 6.0% in response to the higher level of treatment, or 4.1 to 5.9% in response to the lower level of treatment, in the sections of the River downstream from the City of Spokane's discharges. Relative to the 2012 time period, these future planned improvements by the City of Spokane are expected to reduce PCB concentrations in fish of the Spokane River by 4.2 to 7.2%, downstream of the City's discharges.

In comparison to the baseline period, future (2030) projected loadings of PCBs are expected to reduce concentrations of PCBs in water, sediments and fish by 10.9 to 17.4% from baseline levels in the Spokane River downstream from the City of Spokane facilities as a result of implemented and planned upgrades at the City of Spokane facilities. (Reductions of 7.1 to 12.1% are expected to have occurred between the baseline and current time periods. Additional declines in PCB concentrations of between 3.8 to 5.3%, relative to baseline levels, are expected to occur between 2018 and 2030, in response to planned facility upgrades by the City of Spokane. Overall this results in a combined total reduction of 10.9 to 17.4%, relative to baseline levels).

In the section of the Spokane River immediately downstream of the City of Spokane facilities (RM 74.0-58.1), concentrations of PCBs in Largescale Suckers are predicted to reach concentrations of 0.0475 to 0.0489 mg/kg ww in the future as a result of both the highest

and lowest level of treatment, which yielded similar results. For the same section of the River, concentrations of PCBs in Rainbow Trout are expected to reach concentrations of 0.0393-0.0404 mg/kg ww under all treatment scenarios. In Mountain Whitefish, concentrations of PCBs in this section of the River downstream of the City of Spokane facilities are expected to attain concentrations of 0.193-0.199 mg/kg ww in the future in response to both the highest and lowest levels of treatment.

ATTACHMENTS

ATTACHMENT A: CURRICULUM VITAE

Curriculum Vitae of Frank A.P.C. Gobas

Academic Address:

School of Resource and Environmental Management
Faculty of the Environment
Simon Fraser University
8888 University Drive
Burnaby, British Columbia V5A 1S6
Canada
tel. (778) 782-5928; fax (778) 782-4968; email: gobas@sfu.ca

Home Address:

764 Edgewood Road
North Vancouver, BC
V7R 1Y4
Canada
(604) 984-4505

Website: <http://www.sfu.ca/rem/toxicology.html>

Education & Academic Career

- | | |
|-----------|---|
| 2010-2013 | <p>Chair, School of Resource and Environmental Management, Faculty of the Environment, Simon Fraser University.</p> <p>Responsible for the implementation of a Master's and Ph.D. Program in Resource & Environmental Management, a Co-Op program and an undergraduate program in support of the Environmental Science & Environmental Studies curricula at SFU. These programs involve approximately 120 full time equivalent graduate students, 100 full time equivalent undergraduate students, 17 faculty members and 5 staff members.</p> |
| 2004 | <p>Full Professor, School of Resource and Environmental Management, Faculty of Environment, Simon Fraser University.</p> <p>Associate Faculty Member, Biological Sciences, Faculty of Science, Simon Fraser University.</p> <p>Research: Environmental fate, toxicology and risk assessment of pollutants. Bioaccumulation and food-chain transfer modelling and ecosystem based studies of the environmental fate and effects of organic chemicals and mercury.</p> |
| 2002-2005 | <p>Chair, School of Resource and Environmental Management, Faculty of Applied Sciences, Simon Fraser University.</p> |
| 1999-2002 | <p>Chair of Graduate Studies, School of Resource and Environmental Management, Faculty of Applied Sciences, Simon Fraser University.</p> |
| 1996-1997 | <p>Chair, School of Resource and Environmental Management, Faculty of Applied Sciences, Simon Fraser University.</p> |

- 1995 **Associate Professor**, School of Resource and Environmental Management, Faculty of Applied Sciences, Simon Fraser University.
- 1990 **Assistant Professor**, School of Resource and Environmental Management, Faculty of Applied Sciences, Simon Fraser University.
- 1989 **Adjunct Professor**, Department of Civil and Environmental Engineering, University of Windsor.
- 1989 **Senior Research Scientist**, Great Lakes Institute, University of Windsor
- 1988 **Postdoctoral Fellow** at the Great Lakes Institute, University of Windsor.
- 1984-1988 **Ph.D. in Chemical Engineering and Applied Chemistry**
Department of Chemical Engineering and Applied Chemistry & Institute for Environmental Studies, University of Toronto
Dissertation: Bioaccumulation of Hydrophobic Organic Chemicals in Fish
Supervisor : Dr. D. Mackay
Graduated June 6, 1988.
- 1982-1984 **M.Sc. in Environmental Chemistry and Toxicology**
Department of Chemistry, University of Amsterdam
Graduated "cum laude" August 1984
Major : **Environmental Chemistry and Toxicology**
Thesis : Uptake and Bioaccumulation of Hydrophobic Organic Chemicals in Aquatic Organisms
Supervisor : Dr. O. Hutzinger
Minor : **Molecular Toxicology/Pharmacochemistry**
Thesis : The Role of Metabolic Activation by Cytochrome P450 in Covalent Binding of VP16-213 to HeLa-cell Microsomal Proteins
Supervisor : Dr. H.M.S. Pinedo
- 1978-1982 **B.Sc. in Chemistry**
Free University of Amsterdam
graduated December 1981

Academic Awards

- 2011 **Excellence in Review Award**, Environmental Science & Technology 2011
- 1987 **SETAC Best Student Paper Award**, at the 8th annual meeting of the Society of Environmental Toxicology and Chemistry, November 12,

Pensacola, Florida

1987 **J.R. Brown Prize** for research in Occupational and Environmental Health, November 24, 1987.

Professional Experience I

2018-2019	Member of Southern Resident Killer Whale (SRKW) Technical Working Group (TWG) on Contaminants.
2019	Member of expert panel for the Evaluation of the Chemicals Management Plan (CMP).
2019	Chair of session “Very Persistent and Very Bioaccumulative Substances.”. 29 th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Helsinki, Finland, May 26-30, 2019.
2018	Chair of session on “Recent Developments in Bioaccumulation Science for the 45th Canadian Ecotoxicity Workshop. Vancouver, British Columbia. September 30 – October 2.
2015	Chair of SETAC session (with Doris Vidal-Dorsch): “Bioaccumulation in Management and Regulation” 36 th SETAC North America Conference, November 1-5, Salt Lake City, USA.
2015	Chair of SETAC session (with Philip Leber): “Difficult Substances - Their testing and ecological risk assessments” 36 th SETAC North America Conference, November 1-5, Salt Lake City, USA.
2014	Instructor SETAC short course: “Activity Based Environmental Risk Assessment” 35 th SETAC North America Conference, August 10-14, November 9-13, Vancouver, Canada.
2014	Chair of Symposium on “Bioaccumulation risk assessment: Problems and possibilities” 13 th IUPAC International Congress on Pesticide Chemistry, August 10-14, San Francisco, California, US
2014	Chair of SETAC session (with M. Bonnell & J. Arnot): “Bioaccumulation: Science & Regulations” 35 th SETAC North America Conference, August 10-14, November 9-13, Vancouver, Canada.
2010-2011	Environment Canada Board of Review Expert Witness on Decamethylcyclopentasiloxane (D5)
2011	External Evaluation of the Fisheries program of the University of Malaysia at Terengganu
2007-2010	Editor of the Bioaccumulation Science Advisory Group section of the SETAC Globe Journal
2007-2008	Member of the steering committee for organizing a SETAC Pellston Conference on POPs Criteria
2006-2012	Member of the SETAC Bioaccumulation Science Advisory Group
2005	Member of the Aquatic Life Criteria Panel of the US-EPA Science Advisory Board
2004	Director of the Science Advisory Board for Contaminated Sites in British Columbia

2004	Guest Editor: Special Issue of the international journal Environmental Toxicology and Chemistry, Issue 23(10), 2004.
2003	Member of the Science Advisory Board for Contaminated Sites in British Columbia
2003-2009	Member of the UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP): This is the scientific advisory body of the IMO, FAO, UNESCO, IOC, WMO, WHO, IAEA, UN and UNEP on global marine environment & protection.
2003	Session Chair: Bioaccumulation. 2003 SETAC Europe Meeting, Hamburg, Germany.
2002-2005	Chair of the UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 33: Environmental Exposure Models for Application in Seafood Risk Analysis
2001-2005	Member: IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP GESAMP Working Group 33: Environmental Exposure Models for Application in Seafood Risk Analysis
2004	Guest Editor: Special Journal Issue of Environmental Toxicology & Chemistry. Don Mackay Celebratory Issue
2002	Chair: Toxic Substances Research Initiative Scientific Review Committee on POPs
2002	Session Chair: Environmental Modeling. 2002 Aquatic Toxicity Workshop, Whistler, BC.
1999-2002	Member of Environment Canada Technical Advisory Committee for the evaluation of chemicals on the DSL under CEPA 1999
2001	Member of the Editorial Board of the peer-reviewed scientific international journal: Environmental Chemistry
1998 - 2001	Member of the Editorial Board of the peer-reviewed scientific international journal: Environmental Toxicology & Chemistry
1995-current	Member of the Editorial Board of the peer-reviewed scientific international journal: Science of the Total Environment
1993 - 1995	Member of the Editorial Board of the peer-reviewed scientific international journal: Environmental Toxicology & Chemistry
1992 - 1997	Member of the Editorial Board of the peer-reviewed scientific international journal: Bulletin of Environmental Contamination & Toxicology
1997	External Reviewer of Hudson River PCB Contamination Study (Industrial Economics)
1996	Session Chair: Bioavailability. 1996 Annual Meeting of the Society of Environmental Toxicology and Chemistry, Washington DC
1992 – 1995	Co-organizer & Platform Session Chair: 1995 Annual Meeting of the Society of Environmental Toxicology and Chemistry, Vancouver
1995	Symposium Chair: Global Environmental Fate of Organic Pollutants. 1995 Annual Meeting of the Society of Environmental Toxicology and Chemistry, Vancouver
1995	Session Chair: Bioaccumulation. 1995 Annual Meeting of the Society of

	Environmental Toxicology and Chemistry
1990	Lake Ontario Toxics Committee; Member of the Review Panel of the Niagara River/Lake Ontario Fate-of-Toxics Committee
1990	Program Chair, 33rd Annual Conference of the International Association of Great Lakes Research
1989-1992	Member of the Awards Committee of the Society of Environmental Toxicology and Chemistry
1986-2003	Member of the Society of Environmental Toxicology & Chemistry

Professional Experience II : Professional Projects

2015-2018	PCB Pathway Determination For The Hudson River Natural Resource Damage Assessment
2015	Risk assessment of contaminants in migrating salmon. For USEPA.
2014	Expert witness for BENPAT Risk Assessment. For Goodyear Inc.
2011	Food-Web Bioaccumulation Modeling of PCBs in Victoria Harbour. With Azimuth Consulting Inc.
2011	Expert witness for Siloxane D5 Board of Review of Environment Canada
2010	Open Ocean Disposal of Contaminated Sediments in Killer Whale Critical Habitat. With the Department of Fisheries and Oceans
2006	BC Hydro East Ditch Storm water and Receiving Environment Mass Balance Model for PCBs. With Azimuth Consulting Inc.
2005	Total Maximum Daily Loading Model Review for Newark Bay. With Malcolm & Pirnie Ltd.
2004-2005	Consultant to the Petroleum Additives Panel Risk Assessment Task Group (RATG) of the American Chemistry Council.
2004-2005	External Review of the Housatonic River Model Calibration and Validation. With SRA International
2004	External Review of the Lower Passaic River Restoration Study. With Malcolm & Pirnie Ltd.
2004-2007	Development of a Mass Balance Model for PCBs and PBDEs in the Georgia Basin. For Environment Canada
2004-2007	Development of Mass Balance Model for POPs in Burrard Inlet. For the BC Ministry of Water, Lands and Parks
2004-2005	Development of a higher trophic food-web bioaccumulation model as part of the San Francisco Bay TMDL (Total Maximum Daily Loading) for PCBs. For the Clean Estuaries Partnership
2000-2002	Development of a food-web bioaccumulation model for PCBs in San Francisco Bay. For the San Francisco Estuary Institute
1999-2004	Evaluation of Chemicals on the Domestic Substances List for Environment Canada. For Environment Canada
2000-2002	Development of the TMDL for PCBs in San Francisco Bay With the San Francisco Estuary Institute
1999	Dioxin Bioaccumulation Assessment Manual, US-EPA.

1997	Human Health and Ecological Risk Assessment of Homebush Bay Sediments. For Office of Marine Administration (Australia) with EVS Consultants Ltd.
1997	The Applicability and Feasibility of Using a Fugacity Based Approach to Develop a Multi-Media Model in support of the HWIR (Conceptual multi-media model development for waste management units) - For US Office of Solid Waste with Research Triangle Institute
1997-1998	Development of an Environmental Fate Model for PCBs in Commencement Bay, Seattle. For William, Kastner and Gibbs on behalf of General Metals of Tacoma.
1997	Prepared "Bioaccumulation Modelling Review", for <u>US-EPA</u> with Ogden Environmental Ltd.
1997	Prepared Guidance Document for the use of Bioaccumulation Factors in the Great Lakes water Quality Initiative, for <u>US-EPA</u> with Ogden Environmental Ltd.
1995-1996	Developed a "Model of the Fate of Contaminant Discharges in the Burrard Inlet". For <u>Environment Canada</u> with EVS Consultants Ltd.
1995-1996	Contracted to conduct a study entitled "Assessment of the Assimilative Capacity of Saanich Inlet". For the <u>British Columbia Ministry of the Environment & Parks</u> with EVS Consultants
1994	Served on a committee to review the "Southern California Bight Damage Assessment: Food-Web Pathway Study". For <u>US Department of Justice</u>
1992	Developed a computer simulation model of the distribution of organochlorines from pulp mill effluents in the Fraser & Thompson Rivers and food-chains. For the <u>British Columbia Ministry of the Environment & Parks</u> .
1991 – 1992	Prepared a simulation model for pulp mill effluents in the Fraser River in support of the Fraser River Action Plan. For <u>Environment Canada</u>
1990	Contracted to conduct a study of the presence & effects of Persistent Toxic Substances in Human Breast Milk of mothers in the Great Lakes Basin. For the <u>International Joint Commission</u>
1989	Developed models and procedures to set effluent limitations for industrial discharges to the St. Clair River. For the <u>Ontario Ministry of the Environment</u>
1988	Prepared a manual for the assessment of the biosorption, bioaccumulation and food-chain transfer potential of organic chemicals, to be used in MISA. For the <u>Ontario Ministry of the Environment</u>

Research Support Awarded

(years within brackets refers to the duration of the funding; % refers to the fraction of the joint funding allocated to Dr. F. Gobas)

2018-2022	Wetland treatment of Oil Sands Process Water (OSPW)
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	Frank A.P.C. Gobas NSERC-CRD \$304,825 (4 years), 100%
2018-2019	A Framework for Assessing Bioaccumulation and Exposure Risks of Per and Polyfluoroalkyl Substances in Threatened and Endangered Species on Aqueous Film Forming Foam (AFFF)-Impacted Sites. Frank A.P.C. Gobas Department of Defence \$218,000 (1 year), 100%
2018-2021	Improved Characterization Of Partitioning And Biotransformation For Screening Organic Compounds For The Potential To Bioaccumulate In Air-Breathing Species (ECO 41) Wania Frank, Frank Gobas, Jon Arnot European Chemical Industry Council-Long Range Research Initiative \$696,000 (3 years), 46%
2017-2018	Identification and prioritization of contaminants and their sources to Northern and Southern Resident Killer Whales in BC Frank A.P.C. Gobas Department of Fisheries & Oceans \$18,375 (1 year), 100%
2016-2019	Determination of the in-vivo Hepatic, Somatic and Intestinal Biotransformation Rates of Siloxanes D4, D5, D6, L3, L4 and L5 in Rainbow Trout at Varying Exposure Concentrations Frank A.P.C Gobas European Center for Silicone Research \$436,000 (3 years), 100%
2016-2018	Environmental Fate Model for Assessing Waste Water Remediation Capacity A. Cancelli, F. Gobas MITACS & Imperial Oil \$30,000.00 (2 years)
2014-2017	The effect of pre-exposure and mixture-exposure on biotransformation rates of high volume production chemicals Frank A.P.C Gobas Unilever \$ 168,000 (3 years)
2014-2019	Natural and Constructed Wetlands for Pollution Remediation F. Gobas NSERC-Discovery Grant \$ 175,000 (5 years)
2014-2017	Health risk-based evaluation of emerging pollutants in killer whales (Orcinus orca): Priority-setting in support of recovery F. Gobas Department of Fisheries & Oceans \$148,125.00 (3 years)

2015-2016	<p>Development and Testing of a Fugacity Based Treatment Wetland Environmental Fate Model for Assessing Waste Water Remediation Capacity: Model Testing in the Kearl Lake Pilot Treatment Wetland.</p> <p>F. Gobas Imperial Oil \$47,000.00 (2 years)</p>
2012	<p>Activity Based Risk Assessment for Phthalate Esters</p> <p>Gobas, F.A.P.C. American Chemistry Council \$18,000 (1 year)</p>
2013	<p>Development of a Model to Simulate the Fate of Contaminants in Engineered Treatment Wetlands</p> <p>Gobas, F.A.P.C. ExxonMobile \$85,000 (1 year)</p>
2011-2012	<p>Modeling PBDEs in a BC Marine Mammalian Food-Webs</p> <p>Gobas, F.A.P.C. Department of Fisheries and Oceans \$25,000 (1 year)</p>
2011	<p>Derivation of Sediment Target Concentrations for Contaminants at Contaminated Sites</p> <p>Gobas, F.A.P.C. Department of Fisheries and Oceans \$6,000 (1 year)</p>
2011	<p>Fugacity Ratios of Phthalate Esters</p> <p>Gobas, F.A.P.C. American Chemistry Council \$18,000 (1 year)</p>
2010	<p>Open Ocean Disposal of Contaminated Sediments in Killer Whale Critical Habitat</p> <p>Gobas, F.A.P.C. Department of Fisheries and Oceans \$5,000 (1 year)</p>
2010	<p>Sediment Quality Guideline Development for Marine Mammals</p> <p>Gobas, F.A.P.C. Department of Fisheries and Oceans \$6,000 (1 year)</p>
2010	<p>Environmental Pollution in Steller Sea Lions</p> <p>Gobas, F.A.P.C. Department of Fisheries and Oceans \$7,500 (1 year)</p>
2010	<p>Sediment Exposure Model</p> <p>Gobas, F.A.P.C. Environment Canada \$10,000 (1 year)</p>

2009-2013	Biotransformation of Commercial Chemicals in Food-Webs F. Gobas NSERC-Discovery Grant \$ 154,000 (4 years)
2009-2010	Environmental Fate Mono-Alkyl Phthalate Esters Gobas, F.A.P.C. American Chemistry Council \$19,000 (1 year)
2009	Harbour Seal-Sediment Relationship and Guideline Development Gobas, F.A.P.C. Department of Fisheries and Oceans \$9,500 (1 year)
2008-2011	Improving Commercial Chemical Stewardship in Canada F. Gobas (PI), M. Moore and C. Kennedy NSERC-Strategic Grant \$ 194,000 (3years)
2008-2009	Biodegradation of Di-Isodecyl phthalate Ester Gobas, F.A.P.C. Exxon Mobile \$50,000 (1 year)
2008	Harbour Seal-Sediment Relationship and Guideline Development Gobas, F.A.P.C. Department of Fisheries and Oceans \$9,500 (1 year)
2006-2008	Harbour Seal-Sediment Relationship Gobas, F.A.P.C. Department of Fisheries and Oceans \$30,000 (3 years)
2006-2007	Environmental Fate Mono-Alkyl Phthalate Esters Gobas, F.A.P.C. American Chemistry Council \$12,100 (100%)
2006-2011	Environmental Fate of Phthalate Ester Degradation Products F. Gobas NSERC-Collaborative Research Development Grant \$ 224,200 (5 years)
2004-2008	Bioaccumulation of Organic Chemicals in Food-Webs F. Gobas NSERC-Discovery Grant \$ 156,000 / year (4 years)
2004	Development and Application of Models of Chemical Fate in Canada Mackay, D., Wania, F., Gobas, F.A.P.C. Grant from Environment Canada \$45,000 (1 year), 22%
2004-2007	Mass Balance Model for PCBs and PBDEs in the Georgia Basin

	Gobas, F.A.P.C. Grant from Environment Canada \$75,000 (3 years)
2004-2007	Mass Balance Model for POPs in Burrard Inlet Gobas, F.A.P.C. Grant from the BC Ministry of Water, Lands and Air Protection \$75,000 (3 years)
2004-2005	Environmental Fate Mono-Alkyl Phthalate Esters Gobas, F.A.P.C. and M. Ikonomou American Chemistry Council \$203,726 (100% over 3 years)
2004-2005	Development of a Food-web Bioaccumulation model for PCBs in the San Francisco Bay Gobas, F.A.P.C. Contribution from the Clean Estuaries Partnership US\$84,700 (1 year)
2003	Chemical Analysis of POPs of Emerging Concern in Fish Gobas, F.A.P.C. Grant from Department of Fisheries and Oceans \$7,000 (1 year)
2002-2005	Evaluating the Bioavailability of Sedimentary Organic Contaminants in the Marine Environment and it's Implications for Australian Sediment Quality Guidelines Birch, G. and F.A.P.C. Gobas Grant from Australian Research Council \$250,000 (20%, over 3 years)
2002	Chemical Analysis of POPs of Emerging Concern in Fish Gobas, F.A.P.C. Grant from Department of Fisheries and Oceans \$24,000 (1 year)
2001-2002	Food-Chain Bioaccumulation of Phthalate Esters: Part II Mono-alkyl Phthalate Esters Gobas, F.A.P.C. and M. Ikonomou American Chemistry Council \$160,000 (100% over 2 years)
2002-2003	Bioaccumulation of Chemicals of Emerging Concern in Canada's Eastern Arctic Marine Ecosystem Gobas, F.A.P.C. Northern Ecosystem Initiative \$64,000 (over 2 years)
2001	Chemical Analysis of POPs of Emerging Concern in Fish Gobas, F.A.P.C. Grant from Department of Fisheries and Oceans \$16,000 (1 year)
2000-2003	Improving exposure estimates for risk assessment: development and

	validation of an in vitro test of bioavailability
	Moore M. (PI) and Gobas, F.A.P.C.
	NSERC Strategic Grant
	\$131,250 (over 3 years) (40%)
2000	Analysis of Diazinon in Burnaby streams
	Li, P (PI) and F.A.P.C. Gobas
	City of Burnaby
	\$7,000 (50%, over 1 year)
2000-2002	Development of a food-web bioaccumulation model for PCBs in San Francisco Bay
	Gobas, F.A.P.C.
	Contribution from the San Francisco Estuary Institute
	US\$32,000 (1 year)
2000-2003	Development of a Marine Mercury Cycling Model
	Gobas, F.A.P.C. (PI), Cranston R. and B. Brianfirun
	NSERC Strategic Research Grant
	\$190,000 (80%, over 3 years)
2000-2004	Bioavailability of Super-Hydrophobic Organic Chemicals: Measurement, Mechanism and Models
	Gobas, F.A.P.C.
	NSERC Individual Research Grant
	\$140,000 (over 4 years)
2000-2003	Bioaccumulation Modelling
	Gobas, F.A.P.C.
	Grant from Dupont Inc.
	\$75,000 (over 3 years)
2000-2001	Environmental Fate of Mercury in the Gulf of Maine
	Gobas, F.A.P.C.
	Gulf of Maine Research Council Grant
	\$11,400 (over 1 year)
1999-2001	Food-Chain Bioaccumulation of Phthalate Esters
	Gobas, F.A.P.C. and M. Ikonomou
	NSERC Industry Oriented Research Grant
	\$124,332 (over 2 years)
1999-2001	Food-Chain Bioaccumulation of Phthalate Esters
	Gobas, F.A.P.C. and M. Ikonomou
	Grant from Health Canada - Toxic Substances Research Initiative
	\$254,000 (over 2 years)
1998-2001	Development & Verification of an Environmental Fate Model for PAHs in Kitimat arm
	Gobas, F.A.P.C.
	Grant from Alcan Ltd.
	\$ 114,459 (over 3 years)
1999	Analysis of Phthalate Esters
	Gobas, F.A.P.C.

	Grant from Chemical Manufacturers Association \$10,000 (over 1 year)
1998-2000	An in-situ Investigation of the Food-Chain Bioaccumulation Potential of Phthalate Ester Congeners in a Marine Food-Chain Gobas, F.A.P.C. Grant from Chemical Manufacturers Association \$172,500 (over 2 years)
1996-1999	Development & Verification of an Ecosystem-Based Environmental Risk Assessment Model for Industrial Chemicals & Contaminants Gobas, F.A.P.C. NSERC Operating Grant \$82,500 (over 3 years)
1995-1996	Assessment of the Assimilative Capacity of Saanich Inlet B. Powers, S. Davidson, F.A.P.C. Gobas British Columbia Ministry of the Environment, Lands & Parks \$90,000 (25%)
1995-1996	Burrard Inlet Chemical Fate Model Gobas, F.A.P.C., S. Davidson, B. Powers Environment Canada \$80,000 (40%)
1994-1997	Development & verification of an integrated environmental fate, bioaccumulation and a physiologically based internal toxicokinetic model for hazard & risk assessment of pollutant emissions in marine ecosystems Gobas, F (PI), F. Law NSERC Strategic Grant \$ 329,670 (3 years, 60%)
1994-1996	EcoFate Commercialization Plan F. Gobas Simon Fraser University Industry Liaison Office \$17,100 (to date)
1994	Ecotoxicology of Coplanar PCBs in Lake Erie D. Haffner, C. Metcalfe (PI), F. Gobas, M. Dufresne, Evans, Ciborowski, Corkum, MacIsaac, Adeli, Petras, Blais, Weis, McCorquodale. NSERC Great Lakes University Research Fund \$ 222,500 / year (1 year, 6%)
1993-1994	Hazard Assessment of Organic Chemical Emissions by Pulp and Paper Mills in BC F. Gobas BC Ministry of the Environment \$40,000 / year (1 year)
1993-1997	Modelling the Environmental Fate and Effects of Chemical Emissions by Pulp and Paper Mills in the Fraser-Thompson River Basin F. Gobas Environment Canada

	\$150,000 (over 3 years)
1993-1996	Fate and Effects of Organic Chemical Emissions in Aquatic Ecosystems F. Gobas NSERC-Operating Grant \$ 78,000 / year (3 years)
1992-1993	Modelling the Environmental Fate and Effects of Organochlorines discharges by pulp mill in the Fraser River basin BC Science Council \$29,200 /year (1 year) grant
1992-1995	Developing a Quantitative Method for the Interpretation of Biomonitoring Data in Terms of Chemical Loadings to the Great Lakes Gobas, F. (PI) and R. Peterman NSERC Great Lakes University Research Fund \$ 60,000 / year (3 years, 100%)
1992-1995	Ecotoxicology of Coplanar PCBs C. Metcalfe (PI), F. Gobas, D. Haffner, M. Dufresne NSERC Great Lakes University Research Fund \$ 225,000 / year (3 years, 20%)
1992	An Integrated Research-Management Strategy for Aquatic Ecosystems of the Lower Fraser River & Strait of Georgia Gobas, F., A. Farrell and C. Day Simon Fraser University President's Research Grant administered by C. Day \$ 10,400 / year (1 year)
1991-1992	Ecosystem Fate and Effects of Pulp Mill Effluents in the Fraser River: Identification of Research Priorities through the Development of a Computer Simulation Model Environmental & Social System Analysts Ltd and F. Gobas Inland Waters, Environment Canada \$ 60,000 / year (1 year, 11%)
1991-1993	An Integrative Water Quality Impact Assessment Model for the Fraser River F. Gobas BC Science Council \$ 18,000 / year (1.5 years)
1991	NSERC Equipment Grant F. Gobas \$ 33,000 / year (1 year)
1991	Ecotoxicology of Coplanar PCBs F. Gobas, C. Metcalfe (PI), D. Haffner NSERC Great Lakes University Research Fund \$ 75,000 / year (1 year, 20%)
1991	Bioavailability of Dibenzo-p-dioxins and Dibenzofurans in Fish F. Gobas

	Simon Fraser University President's Research Grant \$ 8,600 / year (1 year)
1990-1993	Relating Structure and Properties of Organic Chemicals to Environmental Fate F. Gobas NSERC-Operating Grant \$ 54,000 / year (3 years)
1988-1991	Exposure and Effects of Organic Chemicals in the Huron-Erie corridor D. Haffner (PI) and F. Gobas (PI) Ontario Ministry of the Environment \$ 600,000 / year (3 years, 50%)
1990	Bioaccumulation of Toxics in the Great Lakes Food-Chain F. Gobas Ontario Ministry of the Environment \$ 35,000 / year (1 year)
1990	Persistent Toxic Substances in Human Breast Milk in the Great Lakes Basin F. Gobas International Joint Commission \$ 7,000 / year (1 year)
1990	Fate Modelling in the Niagara River/Lake Ontario F. Gobas, J. Kramer (PI), J. DePinto National Water Research Institute \$ 10,000 / year (1 year, 33%)
1990	Modelling Coliform Discharge & Distribution from Combined Sewer Overflows in the Detroit River J.A. McCorquodale (PI) and F. Gobas National Water Research Institute \$ 21,000 / year (1 year, 10%)
1990	Modelling Effluent Discharge of the West-Windsor Water Treatment Plant in the Detroit River J.A. McCorquodale (PI) and F. Gobas City of Windsor \$ 15,000 / year (1 year, 50%)
1990	Distribution, Trophic Enrichment and Toxicology of Coplanar PCBs in Mink Populations in the Great Lakes Basin G.D. Haffner (PI), R. Lazar, F. Gobas Renewable Resource Research Grant, Ontario Ministry of Natural Resources \$ 22,500 / year (1 year, 50%)

1989	Effluent Limitations for Industrial Load Allocations to the St. Clair River F. Gobas and J.A. McCorquodale (PI) Ontario Ministry of the Environment \$ 13,000 / year (1 year, 50%)
1989	Modelling Food-Chain Transfer of Environmental Contaminants in the Lake St. Clair Ecosystem F. Gobas (PI) Ontario Ministry of the Environment \$ 8,200 / year (1 year)
1988	Food-Chain Transfer of Environmental Contaminants in the Lake St. Clair Ecosystem F. Gobas (PI) Ontario Ministry of the Environment \$ 9,000 / year (1 year)
1988-1989	Biosorption, Bioaccumulation and Food-Chain Transfer of Organic Chemicals F. Gobas and D. Mackay (PI) Ontario Ministry of the Environment \$ 20,000 / year (1 year, 80%)

Teaching Activities

<u>Year</u>	<u>Course</u>	<u>Course Title</u>
2019	REM-610	Applied Environmental Toxicology
2018	REM-445	Environmental Risk Assessment
2017	REM-445	Environmental Risk Assessment
2016	REM-610	Applied Environmental Toxicology
	REM-445	Environmental Risk Assessment
2015	REM-610	Applied Environmental Toxicology
	REM-698	Introduction to Resource Management
2014	REM-664	Directed Studies
	BISC-490	Research Design
	BISC-491	Research Techniques
	BISC-492	Research Reporting
2013	REM-610	Applied Environmental Toxicology
	REM-698	Introduction to Resource Management
	REM-664	Directed Studies
	BISC-490	Research Design
	BISC-491	Research Techniques
	BISC-492	Research Reporting
2012	REM-610	Applied Environmental Toxicology
	REM-661	Special Topics: Environmental Risk Assessment
	REM-698	Introduction to Resource Management

	REM-491	Directed Studies
2011	REM-610	Applied Environmental Toxicology
	REM-661	Special Topics: Environmental Risk Assessment
	REM-698	Introduction to Resource Management
	REM-664	Directed Studies in Resource Management
2010	REM-610	Applied Environmental Toxicology
	REM-661	Special Topics: Environmental Risk Assessment
	REM-698	Introduction to Resource Management
	REM-664	Directed Studies in Resource Management
2009	REM-445	Environmental Risk Assessment
	REM-100	Global Change
	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
2007	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management (4 times)
	REM-698	Introduction to Resource Management
2006	REM-664	Directed Studies in Resource Management
	REM-698	Introduction to Resource Management
2005	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
	REM-698	Introduction to Resource Management
2004	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
	REM-698	Introduction to Resource Management
2003	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
2002	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
2001	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
2000	REM-445	Environmental Risk Assessment
	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
1999	REM-445	Environmental Risk Assessment
	REM-612	Simulation Modelling in Natural Resource Management
	REM-610	Applied Environmental Toxicology
	REM-664	Directed Studies in Resource Management
1998	REM-664	Directed Studies in Resource Management
		The Application of Multi-Media Mass Balance Modeling in Water Quality Management & Risk Assessment” University of Sydney, New South Wales, Australia
1997	REM-610	Management of Contaminants in the Environment
	REM-664	Directed Studies in Resource Management
1996	REM-610	Management of Contaminants in the Environment
1995	REM-612	Simulation Modelling in Natural Resource Management

	REM-602	Advanced Research Seminar in Resource & Environmental Management
	REM-664	Directed Studies in Natural Resource Management: Scientific Expertise vs. Public Perception
1994	REM-801	Research Methods in Resource & Environmental Management
	REM-612	Simulation Modelling in Natural Resource Management
	REM-610	Management of Contaminants in the Environment
	REM-602	Advanced Research Seminar in Resource & Environmental Management
1993	REM-612	Simulation Modelling in Natural Resource Management
	REM-610	Management of Contaminants in the Environment
	REM-664	Directed Studies in Natural Resource Management: Application of Genetic Algorithms in Natural Resource & Environmental Management
1992	REM-612	Simulation Modelling in Natural Resource Management
	REM-610	Management of Contaminants in the Environment
	REM-660	Special Topics in Natural Resource Management: Management of Contaminants in the Environment
1991	REM-612	Simulation Modelling in Natural Resource Management
	REM-646	Environmental & Social Impact Assessment
	REM-660	Special Topics in Natural Resource Management: Management of Contaminants in the Environment
	REM-664	Special Topics in Natural Resource Management: Soil Erosion Modelling in Nepal
	REM-664	Directed Studies in Natural Resource Management: Biomonitoring

Professional Courses Taught

Gobas, F.A.P.C. 2015. Development of a Trophic Magnification Model: Evaluations with Field Data for Persistent and Non-Persistent Organic Chemicals in Aquatic Food Webs. Webinar, March 11, 2015.

Gobas, F.A.P.C. 2014. 1-day Short Course. Activity Based Risk Assessment. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9.

Gobas, F.A.P.C. 2012. Developing Ecologically Relevant Sediment Quality Criteria. 1 day Short Course. 39th Aquatic Toxicity Workshop, Sun Peaks, BC, September 30 to October 3, 2012.

Gobas, F.A.P.C. 2012. Application of Data & Models to Develop Ecologically Relevant Sediment Quality Criteria. 1 day SETAC Short Course. Pacific North West SETAC Regional Conference. Vancouver. April 26-28, 2012.

Gobas, F.A.P.C. 2012. Towards Developing Ecologically Relevant Sediment Quality Criteria. Webinar, February 15, 2012.

Arnot, J.A., Mark Bonnell and Frank A.P.C. Gobas. 2006. BCF and BAF data and models for organic chemicals in aquatic species. European Commission Bureau Training Course on QSARs. July 24, 2006.

Gobas, Frank A.P.C. and J.A. Arnot. 2006. Food-Web Bioaccumulation Modeling. 1 day SETAC Short Course. 27th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Montreal, November 5-9.

Gobas, Frank A.P.C., D. Mackay and K. Solomon. 2008. EcoRisk Assessment Workshop. American Chemical Society. Honolulu, Hawaii, June 5. 1 day Course.

Graduate Student Supervision

Name	Status	Years Supervised or Co-supervised	Title of Project or Thesis	Present Position
Mark Cantu	PH.D. In Progress	2017-		
Kate Fremlin	PH.D. In Progress	2018-		
Nina Piggott	REM In progress	2017-		
John Mora	REM In progress	2017-		
Kapilan Ratneswaran	MET Completed	Supervised 2016-2018	In-Vitro Biotransformation in Fish Liver S9	Environment Canada
Robyn Pearce	REM Completed	Supervised 2016-2018	PCBs in Killer Whales: Local vs Global Sources	Department of Fisheries and Oceans
Karen Compton	REM In progress	Supervised 2015-	Biotransformation and Bioaccumulation of Cyclic Methyl Siloxanes in Fish	Department of Fisheries and Oceans
Marianna DiMauro	REM Completed	Supervised 2015-	Method for Measuring In-Vivo Biotransformation Rates of Hydrophobic Organic Chemicals in Fish	SGS Azimuth Consulting Group
Kate Fremlin	BISC Completed	Committee Member 2015-	Bioaccumulation of Hydrophobic Organic Chemicals in an Avian Terrestrial Food-Chains	Ph.D. student

Wang He	Ph.D. Completed	Co-Supervised 2015-2018	Wetland Remediation	
Alex Cancelli	REM Ph.D. In progress	Supervised 2014-	Wetland Remediation	Ph.D. student
Leslie Saunders	Biology Ph.D. In progress	Supervised 2014-	Biotransformation	Ph.D. student
Jayda Guy	REM Completed	Supervised 2013-2018	Killer whale protection and conservation	DJ
Alex Cancelli	MET Completed	Supervised 2013-2014	Modeling Chemical Fate in Wetlands	Ph.D. student
Kevin Haines	BISC In progress	Committee Member		
Mandy McDougal	REM In progress	Supervised 2012-2016	Bioaccumulation of Ionogenic Substances in Aquatic Food-Webs.	student
Laura Tupper	REM Completed	Supervised 2012-2015	Mixture Toxicity of Phthalate Esters	Environmental analyst with Dillon Consulting
Meara Crawford	REM Completed	Supervised 2011-2015	Activity Based Risk Assessment of Petroleum Hydrocarbon at Contaminated Sites	SGS Azimuth Consulting Group
Tao Eastman	REM Completed	Supervised 2011-2015	Selenium Bioaccumulation in Aquatic Food-Webs.	Golder Associates
Sabine Feldman	MET In progress	Supervised 2012-2015	Risk Assessment of Naphthanic acids	student
Golnar Zandpour	MET Completed	Supervised 2009-2012	Modeling the Environmental Fate and Bioaccumulation of Phthalate Esters and their Metabolites in a Marine Ecosystem	Consultant with Stantec
John Benskin	PDF	2012-2014	Fate of PFCs in Aquatic Food-Webs	Professor U. of Stockholm
Aimee Brisebois	REM Completed	Supervised 2010-2013	Relationship between the BCF and TMF	BC Ministry of the Environment
Pierre Luk	MET In progress	Supervised 2011-	Bioaccumulation model of PBDEs	student
Leslie Saunders	MET In progress	Supervised 2011-2013	The Role of Pre-Exposure on Biotransformation Rates in Fish	Continued into PH.D. program
Gurinder Saroya	Undergrad Research	Supervised 2013	Measuring In Vitro Biotransformation Rates of	unknown

	project		Hydrophobic Chemicals in Fish Liver S9 Using A EVA – Thin Film Dosing Method	
James Oh	Undergrad Research project	Supervised 2013	Assessing the Health of Coral Reefs	unknown
Justin Lo	Ph.D. in progress	Supervised 2007-	Measuring <i>In-Vivo</i> Biotransformation Rates of Hydrophobic Substances in Fish	Student
Mandeep Purewal	MET Completed	Supervised 2010-2012	Derivation of Petroleum Hydrocarbon Wildlands Criteria for British Columbia	Consultant with SNC Lavelin
Jennifer Arblaster	REM Completed	Supervised 2009- 2012	Developing Ecosystem Based Sediment Quality Guidelines in British Columbia	Consultant with Environ Consulting
Hsiao-Yi (Danny) Lee	MET Completed	Supervised 2007-2009	Applying thin-film solid-phase extraction to measure <i>in vitro</i> biotransformation rates of organic chemicals in rainbow trout (<i>Oncorhynchus mykiss</i>)	Consultant with Golder & Associates
Jennifer Trowel	MET completed	Committee member 2009-2010	Biotransformation and modelled bioconcentration factors (BCFs) of select hydrophobic organic compounds using rainbow trout hepatocytes	Azimuth Consultants
Stephanie Ko	REM Completed	Supervised 2007- 2010	Using an <i>in-vitro</i> method for determining metabolic biotransformation rates for hydrophobic organic compounds in rat intestines	Golder & Associates
Andrew Taylor	REM in progress	Supervised 2007- 2010	A conceptual Framework for Developing Criteria for the protection of Wildlands in BC	Imperial Oil
Janey Lam	B.Sci Completed	Committee member 2006-2008	Degradation of DEHP in an in-vitro intestinal medium	Research Scientist SFU
Janey Lam	MET In progress	Committee member 2008	Development of <i>in vitro</i> methods to measure metabolism of hydrophobic chemicals in Rainbow Trout (<i>Onchorynchus mykiss</i>) enterocytes and caco-2 microsomes	Research Scientist SFU
Carlos	Ph.D.	Committee	Land-use impacts in the	Ministry of the

Palomera	in progress Biology SFU	member 2006-2012	Ayuquila river's food webs	Environment, Mexico
Molly Brewis	REM completed	Supervised 2006-2010	Validation of a Food Web Bioaccumulation Model for PCBs in Burrard Inlet, British Columbia	Consultant with Stantec
Juan Jose Alava	Ph.D. in progress	Supervised 2005-2011	Persistent organic pollutants in the Galapagos sea lion (<i>zalophus wolfebaeki</i>)	Post Doctoral Fellow
Yung-Shan Lee	Ph.D. in progress	Supervised 2005-2015	<i>in vitro</i> and <i>in vivo</i> metabolism transformation rates of organic chemicals in rats and fish	Student
Hao-Feng Lai	MET In progress	Supervised 2006 - 2010	Development and Application of a Time-Dependent Food Web Bioaccumulation Model for Organic Chemicals in the Aquatic Ecosystem	Teacher
Peter Kickham	MET Completed	Supervised 2006 - 2010	Biodegradation of Phthalate Esters in sediments	BC Ministry of the Environment
Adebayo Adekola	MET Completed	Supervised 2006 - 2009	An <i>in vitro</i> method for measuring biotransformation rates of chemicals in fish: A study with pyrene.	Consultant with Maxxam
Yongshu Fan	MET Completed	Supervised 2006 - 2008	A Bioenergetic Food- Web Bioaccumulation Model	Health Canada
Colm Condon	REM Completed	Supervised 2003 - 2007	Development, evaluation, and application of a food web bioaccumulation model for PCBs in the Strait of Georgia, British Columbia	Contaminated Sites Assessment Office, BC Ministry of the Environment
Diego Natale	REM Completed	Supervised 2003 - 2007	Modeling the Distribution of PCBs in Vancouver Harbour	Environmental Services Specialist for the Engineering Department (City of Chilliwack)
Margaret McConnell	REM Completed	Supervised 2003 - 2007	Distribution of Mono-Alkyl Phthalate Esters in an Aquatic Food-Web	Azimuth Consultants
Srinivas Sura	MET Completed	Supervised 2002 – 2007	Sorption of Mono-Alkyl Phthalate Esters	Ph.D. student, U. of Saskatchewan

Adrian DeBruyn	PDF Completed	Supervised 2002 – 2005	Bioenergetics of Bioaccumulation	Consultant with Golder Associates Ltd.
Oana Gheorghiu	MET Completed	Committee member 2001 – 2006	Environmental Fate of Personal Care products	BC Ministry of the Environment
Barry Kelly	PhD REM Completed	Supervised 1999 – 2006	Bioaccumulation Potential of Organic Contaminants in an Arctic Marine Food-Web	Professor, University of Singapore
Janice Weightman	MET Completed	Supervised 2001 - 2004	Food-Web Bioaccumulation of Mercury in the Bay of Fundy	Canadian Food Inspection Agency
Luba Vasiluk	PhD Biology Completed	Committee member 2001 – 2006	Oral Bioavailability of Hydrophobic Organic Substances	Dept. of Land Resource Science, University of Guelph
Martin Haefele	PhD Geography Completed	Committee member 1998 – 2004		?
Natasha Hoover	PDF Completed	Supervised 2003 – 2004	Analysis of Phthalate Esters in Water, Sediment and Biota	Environmental Analyst with Axxys
Jaswinder Minhas	MET Completed	Committee member 2002 – 2004	Mobilization of Hydrophobic Contaminants from Soil in a Model Digestive System	Consultant
Deborah Ratzlaff	MET Completed	Supervised 2001 – 2004	Bioconcentration and Biotransformation of Selected Phthalate Esters in Rainbow Trout (<i>Oncorhynchus Mykiss</i>)	Pest Management Regulatory Agency of Health Canada
James Armitage	REM Completed	Supervised 2001 - 2004	Development and Evaluation of a Terrestrial Food Web Bioaccumulation Model	PhD Candidate, University of Stockholm
Javier Maldonado	MET Completed	Committee member 2001 - 2004	The Bioaccumulation of Polychlorinated Biphenyls(PCBs) in a Marine Food Web	Toxicologist, Canadian Food Inspection Agency (Fertilizers Section)
Lizanne Meloche	REM Completed	Supervised 2001 - 2004	Assessing Sediment Quality: A Method to Measure the Fugacity of Hydrophobic Organic Contaminants in Sediment	BC Ministry of the Environment, Consultant Golder

				International
Victoria Otton	REM Completed	Supervised 1999 - 2004	A Method to Measure the Sorptive Capacity of Sediment and Plankton for Selected Organochlorines	Research Associate, Environmental Toxicology Group, SFU
Curtis Eickhoff	PhD Biology Completed	Committee member 1994 - 2004	Studies of Polycyclic Aromatic Hydrocarbons in Dungeness Crabs: Biomonitoring, Physiologically Based Toxicokinetic Model, and Human Health Risk Assessment	Director Ecotoxicology, Cantest Ltd.
Blair McDonald	MET Completed	Committee member 2001 – 2004	Comparison of Porewater and Elutriate Bivalve Larval Development Toxicity Testing in a Sediment Quality Triad Framework	Consultant with Golder International
Jon Arnot	MET Completed	Supervised 2000 -2003	A Bioaccumulation Model of Organic Chemicals in Aquatic Ecosystems	PDF, University of Toronto
Jing Hongwhu	PDF Completed	Supervised 2000 - 2003	Analysis of Phthalate Esters in Environmental Media	PDF at UC Davis
Anne Morin	REM Completed	Supervised 2000 - 2003	Distribution of Phthalate Esters in a Marine Mammal Food Chain from Canada's Eastern Arctic	Health Canada
Ryan Stevenson	REM Completed	Supervised 2000 - 2003	Development and Application of a Model Describing the Bioaccumulation and Metabolism of Polycyclic Aromatic Hydrocarbons in a Marine Benthic Food Web	Environment Canada
Glenys Webster	REM Completed	Supervised 2000 - 2003	Dietary Uptake and Biotransformation of Phthalate Esters in Staghorn Sculpin	PDF, Faculty of Health, SFU
Elsie Sunderland	PhD REM Completed	Supervised 1997 - 2003	Development of a Marine Mercury Cycling Model for Passamaquoddy Bay, New Brunswick	Professor, Harvard

Katherine Neufield	MET Completed	Committee member 2000 - 2002	Development of an Uptake Assay for Gamma-Aminobutyric Acid (GABA) Using Mouse Brain Synaptoneurosomes and its Use in the Investigation of Potential Effects of Oleamide	Toxicologist, Pest Management Regulatory Agency, Health Evaluation Division, Health Canada
Cheryl Mackintosh	REM Completed	Supervised 1998 - 2002	Distribution of Phthalate Esters in a Marine Food Web	Environmental Scientist, Azimuth Consulting
Darren Sherbot	REM Completed	Supervised 1995 - 2002	A Retrospective PCDD/F Loading Inventory and Environmental Risk Assessment for Kamloops Lake and the Thompson River Using a Multimedia Exposure Model	BC Hydro
Daniel Ricard	REM Completed	Supervised 1996 - 2000	Application of a Genetic Algorithm to Calibrate a Food Web Bioaccumulation Model of Contaminants	PDF, Dalhousie
Dale Marshall	REM Completed	Supervised 1996 - 1999	An Ecological Risk Assessment of Dioxins and Furans Discharged by Fraser and Thompson River Pulp and Paper Mills	Center for Policy Alternatives
Barry Kelly	REM Completed	Supervised 1996 - 1999	Trophic Transfer of Persistent Organic Pollutants in an Arctic Tundra Ecosystem	Professor National University of Singapore
Laura Maclean	REM Completed	Supervised 1995 - 1999	The Role of Sediment Diagenesis in Promoting Chemical Disequilibria for Organic Contaminants in Aquatic Systems	Environment Canada
Glenn Harris	PhD REM Completed	Supervised 1994 - 1999	Assessment of the Assimilative Capacity of Kitimat Arm, British Columbia : A Case Study Approach to the Sustainable Management of Environmental Contaminants	Director Research Capital Regional District, Victoria

Dominica Babicki	REM Completed	Supervised 1993 - 1999	The Jurist and the Ecologist: Shifting Paradigms in the International Law of Fisheries Conservation and Exploitation	Claims Researcher
Katherine Beavis	REM Completed	Supervised 1993 - 1998	Developing Sustainability : An Evaluation of Reforestation Projects in Tribal India	Unknown
Lauren Donnelly	MSc. Geography Completed	Committee member 1993 – 1998	Comparison of Rainfall-Runoff Modelling Techniques in Small Forested Catchments	Unknown
John Wilcockson	MSc. Biology Completed	Co-Supervised with T. Farrell 1995 - 1998	Gastro-Intestinal Magnification and Dietary Bioavailability of Chlorinated Organic Contaminants/Xenobiotics: Implications For Biomagnification	Consultant with Hatfield Consultants
Clare Wiseman	REM Completed	Supervised 1994 - 1997	A Risk Balance Analysis of Dioxin and Furan Related Shellfish Closures for Aboriginal Coastal Communities in British Columbia	Professor University of Toronto
David Maguire	REM Completed	Supervised 1993 - 1997	Combining Simulation Modelling and Statistical Power Analysis to Evaluate and Optimize Contaminant Monitoring Programs in Lake Ontario	Washburn & Gillis Associates, Fredericton
Melanie Haggart	REM Completed	Supervised 1992 - 1997	Organochlorine Management Policy in Canada : The Challenge of Applying Science to Contaminant Management	Ministry of Natural Resources, Nova Scotia
Peiwen Qiao	PhD Biology Completed	Committee member 1991 – 1998	Uptake, Bioavailability, and Bioaccumulation of Lipophilic Xenobiotics in Juvenile Rainbow Trout: An Assessment of the Role of Gills and Suspended Particles as a Source of Contaminants	Unknown
Sherry Walker	REM Completed	Supervised 1993 - 1996	Water Quality Guidelines: Are They Safe?	Environment Canada, Ottawa
Gary Lawrence	REM Completed	Supervised 1992 - 1996	A Reevaluation of Quantitative Risk Assessment Methodology for Dioxin in the Fraser River Basin	EVS Consultants, North Vancouver

Kent Lien	REM Completed	Supervised 1992 - 1996	Development and Application of an Environmental Fate and Food-Web Bioaccumulation Model for Organochlorine Emissions from Pulp Mills in the Fraser-Thompson River Basin	Golder Associates, Calgary
Cherie Gelowitz	REM Completed	Supervised 1993 - 1995	An Ecological Risk Assessment of the Effects of Polychlorinated Biphenyl, Dibenzo-P-Dioxin and Dibenzofuran Congeners on the Survival of the Early Life Stages of Lake Trout (Salvelinus Namaycush) in Lake Ontario	Ph.D. student, University of Alberta
Ryan Hill	REM Completed	Co-Supervised 1993 - 1995	Dealing with Scientific Uncertainties in the Management of Chemical Substances	Azimuth
Heather Morrison	PhD Biology U of Windsor Completed	Committee Member 1991 – 1995	The Effects of Zebra Mussels (Dreissena Polymorpha) on the Distribution and Dynamics of Polychlorinated Biphenyls in the Western Lake Erie Food-Web	Environment Canada
Michael Z'Graggen	REM Completed	Supervised 1991 - 1994	Temporal Response of the Lake Ontario Ecosystem to Virtual Elimination of PCBs	Golder Associates, Calgary
Trent Berry	REM Completed	Committee Member 1990 - 1993	Ecosystem health : towards definition & assessment	Unknown
John Pasternak	REM Completed	Supervised 1990 - 1993	A Chemical Fate Model for Organic Chemical Emissions from Pulp and Paper Mills in the Fraser-Thompson River System	Health Protection Branch, Environment Canada
Catherine Rogers	REM Completed	Committee Member 1990 - 1993	Describing Landscapes: Indices of Structure	Unknown

Ramona Helm (Duncan)	REM Completed	Supervised 1980 - 1993	A Dynamic Chemical Fate Model for 2,3,7,8-Tetrachlorodibenzo-p-dioxin and 2,3,7,8-Tetrachlorodibenzofuran Emitted from Pulp and Paper Mills in the Fraser River System, British Columbia	Department of Fisheries & Oceans, Ottawa
Bonnie Antcliffe	REM Completed	Committee Member 1990 - 1992	Impact Assessment and Environmental Monitoring: The Role of Statistical Power and Decision Analysis	Unknown
Jerry Rolls	REM Completed	Committee Member 1990 - 1992	Estimating Soil Erosion in the Middle Hills of Nepal	Unknown
Debra Corns	REM Completed	Committee Member 1989 - 1992	Toward a Contaminated Sites Review Process for British Columbia	Unknown
Jan Campfens	REM Completed	Committee Member 1988 - 1992	Modelling the Effluent and Cost Impacts of Technological Options in the BC Pulp and Paper Sector Using the ISTUM Technology Simulation Model	Unknown
Donna Bedard	MSc. Biology U of Windsor Completed	Committee Member - 1990	Factors Influencing the Bioaccumulation of Chlorinated Hydrocarbons by Hexagenia Nymphs (Ephemeroptera: Ephemeridae)	Ontario Ministry of the Environment
Craig Hebert	MSc. Biology U of Windsor (Completed)	Committee Member - 1990	Factors Regulating Organochlorine Contaminant Levels in Forage Fish from the St. Clair and Detroit Rivers	Canada Wildlife Services
Xin Zhang	PDF (Completed)	Supervised 1992 - 1994	Environmental Modelling	Environmental Modeler, US-EPA
Zhong Ping Lin	PDF (Completed)	Supervised 1997 - 1999	Analysis of Phthalate Esters in Biota	Avantix Laboratories, Inc.

Other Student Supervision

1994 Carolyn Taylor : NSERC Undergraduate Fellowship, SFU

- 1989 E.J. McNeil : Honours Project, Department of Chemistry and Biochemistry, University of Windsor
- 1989 S.C. Yousuff : Honours Project, Department of Biology, University of Windsor.

External Doctoral Examinations

- 2000 Philip Mayer: University of Utrecht, Research Institute of Toxicology, Ph. D. Thesis
- 2000 Agnes Oomen: University of Utrecht, Research Institute of Toxicology, Ph. D. Thesis
- 2005 Yushan Su, Department of Chemical Engineering & Applied Chemistry, University of Toronto, Ph. D. Thesis
- 2005 Joline Widmeyer, Department of Biological Sciences, Simon Fraser University, Ph. D. Thesis
- 2005 Chris Golding, University of Sydney, Sydney, Australia, Ph. D. Thesis
- 2010 Seiedeh Aghileh Mirsadeghi, University Putra Malaysia, Ph. D. Thesis
- 2011 Mark Ross, University of Alberta, Ph. D. Thesis
- 2012 Holly Lee, University of Toronto, Ph.D. thesis
- 2013 Ong Pei Thing, University of Malaysia, Ph.D. thesis
- 2018 Chun Chen, City University of Hong Kong, Ph.D. thesis

Internal Examinations

- 2012 Parisa Ebrahimi Jozdani. Chemistry, Master Thesis

University Service

Academic Integrity Advisor
 Member of the Curriculum Committee of the Faculty of the Environment
 Chair of Undergraduate Studies of Resource & Environmental Management
 Member of Simon Fraser University Faculty Restructuring Task Force
 Director, School of Resource & Environmental Management
 Member of the Senate Graduate Studies Committee
 SFU Northern Studies Committee
 NSERC adjudication Committee
 Member of Search Committee for CRC Tier II Chair
 Chair of Graduate Studies
 Director, School of Resource & Environmental Management
 Member of Search Committee for the Dean of the faculty of Applied Sciences (January 1996 - June 1996)
 Chair of Undergraduate Studies Committee

Chair of REM-GIS Laboratory Committee
Chair of Search Committee for the position in “Spatial Analysis & GIS”
Chair of Search Committee for the position in “Social Science”
Chair of REM Faculty Executive Committee
Chair of REM Departmental Tenure Committee
Member of the Undergraduate Studies Committee
REM representative of the Science Library Users Committee
REM representative of Faculty of Applied Science Computer Users Committee
Member of Graduate Studies Committee
Member of the Steering Committee for the preparation of a Green Plan Tri-council research
proposal
Chair Computer Room Committee
Acting Director
Acting Graduate Studies Committee Chair
Chair REM Space Allocation Committee
REM Executive Committee
REM Graduate Admissions Committee
REM Departmental Tenure Committee
REM Committee for the preparation of the Brochure
REM Search Committee for Tourism Faculty Position
REM Search Committee for GIS Faculty Position

LIST OF PUBLICATIONS

BY

FRANK A.P.C. GOBAS

REFEREED PUBLICATIONS SUBMITTED & UNDER REVIEW

Gobas, F.A.P.C., Y.S. Lee, J.C. Lo, T.F. Parkerton. 2019. A Toxicokinetic Framework and Analysis Tool For Interpreting OECD 305 Dietary Bioaccumulation Tests. Environ. Toxicol. Chem. Submitted.

Cancelli, A.M., F.A.P.C. Gobas. 2019. Treatment Efficiencies Of Oil Sands Process Wastewater Pollutants In The Kearl Treatment Wetland. Water Research. Submitted

Jennifer J. Trowell, Frank A. P. C. Gobas, Margo M. Moore and Christopher J Kennedy. 2019. The effect of environmental temperature on in-vitro estimates of elimination rate constants and bioconcentration factors of hydrophobic chemicals in fish. Chemosphere Submitted.

Lo J.C., Y.S. Lee, D.A. Campbell, S.V. Otton, F.A.P.C. Gobas. 2019. In Vitro to In Vivo Extrapolation of Biotransformation Rates of Hydrophobic Chemicals in the Fish Body. Environ. Toxicol. Chem. Submitted.

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Cancelli, A.M., F.A.P.C. Gobas, W. Qian, B.C. Kelly. 2018. Development And Evaluation Of A Mechanistic Model To Assess The Fate and Removal Efficiency Of Hydrophobic Organic Contaminants In Horizontal Subsurface Flow Treatment Wetlands. Water Research. <https://doi.org/10.1016/j.watres.2018.12.020>

Saunders L.J., S. Fontanay, J.W. Nichols, F.A.P.C. Gobas. 2018. Concentration-Dependence Of In Vitro Biotransformation Rates Of Hydrophobic Organic Sunscreen Agents In Rainbow Trout S9 Fractions: Implications For Bioaccumulation Assessment. Environ. Toxicol. Chem. DOI 10.1002/etc.4342.

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Gobas, F.A.P.C. and Mackay, D. 1985. Progress toward understanding the Phenomena of Hydrocarbon Bioaccumulation. Proceedings of the Eighth Annual Arctic Marine Oil Spill Program Technical Seminar (1985), Edmonton, Published by Environment Canada, Ottawa, pp 91-103.

OTHER PUBLICATIONS

Gobas, F.A.P.C. 1995. Environmental Chemistry at the Second SETAC World Congress. SETAC News 15 (3): 1-3.

S AT SCIENTIFIC MEETINGS

Cancelli A.M., F.A.P.C. Gobas. 2019. The removal of organic contaminants from OSPW in the Kearl Treatment Wetland. 11th Western Canadian Symposium on Water Quality Research. Edmonton, May 10.

Fremelin K., J.E. Elliott, K.G. Drouillard, P.A. Martin, F.A.P.C. Gobas, D. Green. 2018. Assessing Trophic Magnification of Cyclic Methyl Siloxanes in a Terrestrial Food-Web of an Avian Top Predator, the Cooper's Hawk. 39th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Sacramento, California, November 4–8.

Saunders L.J., A.D. Hoffman, P.N. Fitzsimmons, J.W. Nichols, F.A.P.C. Gobas. 2018. Quantitative In Vitro To In Vivo Extrapolation Of Biotransformation Rates For Bioaccumulation Assessment: Focus On Organic Sunscreen Agents In Trout. 39th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Sacramento, California, November 4–8.

Cancelli A., F.A.P.C. Gobas. 2018. A Model Of Contaminant Removal From Oil Sands Process Affected Water In The Kearl Treatment Wetland. 39th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Sacramento, California, November 4–8.

Cantu, M., F.A.P.C. Gobas. 2018. Assessment Of Bioaccumulation Potential Of Very Hydrophobic Compounds In Rainbow Trout And The Role Of Metabolism. 39th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Sacramento, California, November 4–8.

DiMauro M., F.A.P.C. Gobas, C.D. Kennedy. 2018. Development And Application Of An In Vivo Test For Estimating Biotransformation Rate Constants And Bioconcentration Factors Of Hydrophobic Organic Chemicals In Fish. 45th Canadian Ecotoxicity Workshop. Vancouver, British Columbia. September 30 – October 2.

Cancelli, A. M., Gobas, F. A.P.C. (2018). Quantifying the removal of polycyclic aromatic hydrocarbons in the Kearl Treatment Wetland. Canadian Oil Sands Innovation Alliance, Oil Sands Innovation Summit, Calgary, AB.

Cancelli, A. M., Gobas, F. A.P.C. (2018). Model performance evaluation using passive samplers at the Kearl Treatment Wetland. Canadian Oil Sands Innovation Alliance, Science Workshop: Oil Sands Process Wastewater Characterization, Identification, and Treatment, Calgary, AB.

Cancelli, A. M., Gobas, F. A.P.C., Qian, W., Kelly, B. C. (2017). An evaluative model to assess the fate and effects of neutral organics contaminants in treatment wetlands. Wetland Pollutant Dynamics and Control, 7th International Symposium, Big Sky, MT.

Fremlin K., J. Elliott, K.G. Drouillard, F.A.P.C. Gobas, D. Green. 2018. Trophic Magnification of Perfluorinated Compounds Within a Terrestrial Food-Web of An Avian Top Predator, the Cooper's Hawk (*Accipiter Cooperii*). 45th Canadian Ecotoxicity Workshop. Vancouver, British Columbia. September 30 – October 2.

Pearce R., F.A.P.C. Gobas, J.J Alava. 2018. Bioaccumulation of PCBs in the Southern Resident Killer Whale food – web. 45th Canadian Ecotoxicity Workshop. Vancouver, British Columbia. September 30 – October 2.

Saunders L.J., J.W. Nichols, F.A.P.C. Gobas. 2018. Quantitative in vitro to in vivo extrapolation of biotransformation rates for bioaccumulation assessment: Focus on organic sunscreen agents in trout. 45th Canadian Ecotoxicity Workshop. Vancouver, British Columbia. September 30 – October 2.

Fremlin, K. Elliott, J.E., Green, D., Drouillard, K.G., Gobas, F.A.P.C. 2017. An assessment of POPs bioaccumulation in the Terrestrial Food-Web of An Avian Top Predator, the Cooper's Hawk (*Accipiter Cooperii*). 28th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Rome, Italy, May 13-17.

Gobas F.A.P.C., M. Dimauro, K. Compton, Y.S. Lee, S.V. Otton, J.C. Lo, G. Allard. 2018. Application of Aqueous and Dietary In-Vivo Bioaccumulation Tests to Determine Biotransformation Rates, Elimination Rates and other Bioaccumulation Metrics. 28th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Rome, Italy, May 13-17.

Gobas F.A.P.C. 2018. Trophic Magnification Factors of Cyclic Siloxanes in Aquatic Environments: Data & Models. cVMS Workshop in Norway. CES Silicones Europe (CES) and Norsk Industri. Oslo, March 9.

Pearce R., F.A.P.C. Gobas. 2018. Sources, spatial variability and uptake of Polychlorinated biphenyls (PCBs) in Southern Resident killer whales. 2018 Salish Sea Ecosystem Conference (SSEC), Seattle, WA, April 4-6, 2018.

Fremlin, K. Elliott, J.E., Green, D., Drouillard, K.G., Gobas, F.A.P.C. 2017. An assessment of POPs bioaccumulation in the Terrestrial Food-Web of An Avian Top Predator, the Cooper's Hawk (*Accipiter Cooperii*). SETAC Latin America 12th, Biennial Meeting. September 7-10. Santos, São Paulo, Brazil.

Saunders L.J., A.D. Hoffman, P.N. Fitzsimmons, J.W. Nichols, F.A.P.C. Gobas. 2017. Testing in vitro to in vivo extrapolation approaches for assessing biotransformation rates and bioaccumulation factors in fish. 38th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Minneapolis, Minnesota November 12–16.

Saunders L.J., A.D. Hoffman, P.N. Fitzsimmons, J.W. Nichols, F.A.P.C. Gobas. 2017. Inclusion of gastrointestinal biotransformation in in vitro to in vivo extrapolation models for bioaccumulation assessment. 38th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Minneapolis, Minnesota November 12–16.

Fremlin K., J. Elliott, K.G. Drouillard, F.A.P.C. Gobas, D. Green. 2017. Trophic magnification of POPs within a terrestrial food-web of an avian top predator, the Cooper's hawk (*Accipiter Cooperii*). 38th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Minneapolis, Minnesota November 12–16.

Tillmanns A., J. Lo, F.A.P.C. Gobas, A. Azizishirazi. 2017. Marine Sediment Quality Guideline for PCBs – Updating Guidelines Using Multiple Lines of Evidence. 44th Canadian Ecotoxicity Workshop, October 1-4, Guelph, Ontario.

Saunders L.J., P. Fitzsimmons, J.W. Nichols, F.A. Gobas. 2017. In Vitro Hepatic And Gastro Intestinal Biotransformation Data For Hydrophobic Chemicals In Fish: Consideration Of Gastrointestinal Biotransformation In In Vitro To In Vivo Extrapolation Models. 27th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Brussels, Belgium, May 7-11.

Gobas F.A.P.C., Y.S Lee, D.H.Y. Lee, J.C. Lo, L.J. Saunders, S.V. Otton. 2017. Development, Testing And Application Of An In Vitro To In Vivo Extrapolation Approach For Assessing Biotransformation Rates And Bioaccumulation Factors In Fish And Mammals: Lessons Learned. 27th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Brussels, Belgium, May 7-11.

Gobas F.A.P.C. 2017. Scientific Advancements in Evaluating Chemicals for POPs (and PBTs). United Nations: Meetings of the conferences of the parties to the Basel, Rotterdam and Stockholm conventions. Geneva, Switzerland, April 24-May 5.

McDougall, M.R.R. and Gobas, F.A.P.C. 2017. Developing A Trophic Magnification Model For Perfluorinated Alkyl Substances In A Marine Food Web. 26th Pacific Northwest-SETAC Annual Conference. Anchorage, Alaska, April 20-22.

Gobas F.A.P.C. 2017. The Application of a Toxicokinetic Approach to B Assessment: Lessons Learned & Path Forward. European Centre for Ecotoxicology and Toxicology of Chemicals. Brussels, Belgium, May 4-5.

Cancelli, A. M., Gobas, F.A.P.C (2016). An evaluative model to assess the fate and effects of contaminants in treatment wetlands. Canadian Oil Sands Innovation Alliance, Pilot Treatment Wetland Scoping Workshop, Teck Resources, Calgary, AB.

Justin Lo, Yung-Shan Lee, Gayatri Allard, Dave Campbell, Frank Gobas. 2016. In Vitro-In Vivo Extrapolation Of Biotransforming Hydrophobic Chemicals In The Fish Body. 43th Canadian Ecotoxicity Workshop. Edmonton, Alberta. September 25-28.

Gobas F.A.P.C., J. Kim, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. A Novel Spatial Aquatic Food-Web Bioaccumulation for Bridging Field Study Data and Regulatory Decision Making. 37th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Orlando, Florida, November 6–10.

Nichols J.W., L.J. Saunders, F.A.P.C. Gobas. 2016. Physiologically based modeling of hepatic and gastrointestinal biotransformation in fish. 37th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Orlando, Florida, November 6–10.

Kim J., F.A.P.C. Gobas, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. Integration of Important Processes into a Novel Spatial Aquatic Food-Web Model for Accurate Assessment and Measurement of Chemical Bioaccumulation. 37th Annual Meeting of the Society

of Environmental Toxicology and Chemistry in North America, Orlando, Florida, November 6–10.

Saunders L.J., S. Fontanay, F.A.P.C. Gobas. 2016. Concentration dependence of in vitro biotransformation rates: Hepatic biotransformation of organic sunscreen agents in rainbow trout. 37th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Orlando, Florida, November 6–10.

Saunders L.J., A.D. Hoffman, J.W. Nichols, F.A.P.C. Gobas. 2016. Concentration dependence of in vivo biotransformation rates of organic sunscreen agents in rainbow trout following a dietary Exposure. 37th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Orlando, Florida, November 6–10.

Justin Lo, Yung-Shan Lee, Gayatri Allard, Dave Campbell, Frank Gobas. 2016. In vitro-in vivo extrapolation of biotransforming hydrophobic chemicals in the fish body. 43rd Canadian Ecotoxicity Workshop, Edmonton, September 25-28. Won First Price for student poster presentation.

Tupper-Ring, L.F., S.V. Otton, F.A.P.C. Gobas. 2016. Application of Thermodynamic Activity to assess the Environmental Risks of Phthalate Ester Mixtures. 43rd Canadian Ecotoxicity Workshop, Edmonton, September 25-28.

F.A.P.C. Gobas, J. Kim, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. New Evaluation Methods for PBT Chemicals and POPs: Development of a Multi-Box AquaWeb Model for Bioaccumulation Assessment. ICCA-LRI Workshop 2016, Awaji Island, Japan, June 13-16

Kim J., F.A.P.C. Gobas, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. Development of Multibox-AQUAWEB Model for Prediction of Trophic Magnification Factors Influenced by Spatial Concentration Gradients, Species Migration, and Field Sampling Design. ICCA-LRI Workshop 2016, Awaji Island, Japan, June 13-16

Kim J., F.A.P.C. Gobas, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. Development of Multibox-AQUAWEB Model for Prediction of Trophic Magnification Factors Influenced by Spatial Concentration Gradients, Species Migration, and Field Sampling Design. 26th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Nantes, France, May 22-26.

Gobas F.A.P.C., J. Kim, J.A. Arnot, D.E. Powell, R.M. Seston, K.B. Woodburn. 2016. Measuring Trophic Magnification Factors: Role of Spatial Concentration Gradients, Disequilibria and Field Sampling Design. 26th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Nantes, France, May 22-26.

Al-Marri S., F.A.P.C. Gobas, A. Cancelli. 2016. A Model for Assessing the Fate of Contaminants in Constructed Wetlands. 26th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Nantes, France, May 22-26.

Arblaster J., J.M. Conder, E. Bizzotto, F. Santoro and F.A.P.C. Gobas. 2015. Development of a Bioaccumulation Model for DDTs in a Pelagic Food Web. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Gobas, F.A.P.C., J.C. Lo, D. Campbell, C.J. Kennedy. 2015. Gastro-intestinal and Somatic Biotransformation in Fish: Implications on BCF and BMF Measurements and Regulatory Interpretation. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Fan Y., A. de Bruyn, F.A.P.C. Gobas. 2015. A Bioenergetic Bioaccumulation Model for Persistent Organic Pollutants in Aquatic and Terrestrial Food Webs. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Gobas, F.A.P.C., J.C. Lo. 2015. A Proposed Model for the Interpretation of Exposure Data from the New OECD305 Bioaccumulation Test Guideline. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Gobas, F.A.P.C. 2015. The Problem with Super-Hydrophobic Chemicals. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Fan Y., F.A.P.C. Gobas. 2015. A bioenergetic/bioaccumulation model for persistent organic pollutants in aquatic and terrestrial food webs. 36th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Salt Lake City, Utah, November 1–5.

Gobas, F.A.P.C., L.F. Tupper-Ring and S.V. Otton. 2015. Application of the thermodynamic activity approach. 2015. ECETOC Workshop On Defining The Role Of Chemical Activity In Environmental Risk Assessment Within The Context Of Mode Of Action: Practical Guidance And Advice, Snowbird, Utah, October 29-30.

Jaeshin Kim, Frank A. P. C. Gobas, Jon A. Arnot, David E. Powell¹, Rita M. Seston¹, Kent B. Woodburn¹. 2015. Development of Multibox-AQUAWEB Model for Prediction of Trophic Magnification Factors Influenced by Spatial Concentration Gradients, Species Migration, and Field Sampling Design. 25th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Barcelona, Spain, May 3-7.

Gobas, F.A.P.C., Jaeshin Kim, Jon A. Arnot, David E. Powell, Rita M. Seston, Kent B. Woodburn. 2015. Measuring Trophic Magnification Factors: Role of Spatial Concentration Gradients, Disequilibria and Field Sampling Design. 25th Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Barcelona, Spain, May 3-7.

Gobas, F.A.P.C., L.F. Tupper-Ring and S.V. Otton. 2015. Application of thermodynamic activity to assess human exposure and health risks of phthalate esters in consumer products. PacificChem 2015. The International Chemical Congress Of Pacific Basin Societies 2015, Honolulu, Hawaii, USA December 15 - 20, 2015

Gobas, F.A.P.C. 2015. Assessment of the exposure and environmental health risks of siloxanes: The case of D5. PacificChem 2015. The International Chemical Congress Of Pacific Basin Societies 2015, Honolulu, Hawaii, USA December 15 - 20, 2015

Mackay D., F.A.P.C. Gobas, J.A. Arnot. 2015. Human and environmental risk assessment: A chemical fugacity and activity approach. PacificChem 2015. The International Chemical Congress Of Pacific Basin Societies 2015, Honolulu, Hawaii, USA December 15 - 20, 2015

Saunders, LJ, Fontanay S, Gobas FAPC. 2015. 'Predicting the bioaccumulation of organic sunscreen agents in rainbow trout using measured in vitro biotransformation rates'. Poster Presentation. Canadian Ecotoxicity Workshop. Saskatoon, SK, October 4-7.

Gobas, F.A.P.C. 2015. Application of Chemical Activity for Chemical Safety Assessment & Management. Does it work? International Council of Chemical Association (ICCA)-LRI and U.S. Environmental Protection Agency (EPA) Workshop, New Orleans, Louisiana, June 16-17, 2015.

Gobas, F.A.P.C. 2015. The World of Chemicals. Workshop on "Recovering BC's marine mammals by tackling pollution." Vancouver, May 20-22, 2015.

Gobas F.A.P.C, J. Arnot, J. Kim, D.E. Powell, K. Woodburn, D. Mackay and R. Seston. 2015. Using the AquaWeb Bioaccumulation Model for Evaluating / Including Field Bioaccumulation Data. ECHA Expert PBT Group. Helsinki, May 12, 2015.

J.C. Lo, G. Allard, C.J. Kennedy, S.V. Otton, D. Campbell, F.A.P.C. Gobas. 2014. Testing in vitro to in vivo extrapolation methods for the biotransformation of very hydrophobic chemicals in trout. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

L. Tupper-Ring, S. Otton, F.A.P.C. Gobas. 2014. Application of thermodynamic activity and fugacity to assess the environmental risks of phthalate ester mixtures. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

F.A.P.C. Gobas. 2014. Activity-Based Analysis of the Environmental Toxicity of Diaryl Phenylenediamines. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

M.A. Crawford F.A.P.C. Gobas. 2014. Application of Activity in Risk Assessment and Criteria Development for Petroleum Hydrocarbon Mixtures. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

A.M. Cancelli, F.A.P.C. Gobas. 2014. An evaluative model for assessing fate and effects of contaminants in engineered wetlands. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

J. Alava, F.A.P.C. Gobas. 2014. A Marine Food Web Bioaccumulation model for Cesium 137 in the Pacific Northwest. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

J.C. Lo, G. Allard, C.J. Kennedy, S.V. Otton, D.A. Campbell, F.A.P.C. Gobas. 2014. In vitro biotransformation of hydrophobic chemicals in trout liver s9 homogenates: concentration dependence of biotransformation rates. 35th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Vancouver, Canada, November 9 – 13.

L. Tupper-Ring, S. Otton, F.A.P.C. Gobas. 2014. Application of thermodynamic activity and fugacity to assess the environmental risks of phthalate ester mixtures. 41st Aquatic Toxicity Workshop, Ottawa, Ontario, Canada, September 28 – October 1.

J.A. Arnot, F.A.P.C. Gobas, J. Nichols, M. MacLeod, E. Papa, K. Borgå, H. Laue, P. Leonards. 2014. Bioaccumulation Assessment: Developing Frameworks and Finding Common Ground. Cefic-LRI Workshop on Recent Scientific Developments in Bioaccumulation Research. Helsinki, September 24.

Gobas, F.A.P.C. and J.A. Arnot. 2014. Bioaccumulation Metrics. Cefic-LRI Workshop on Recent Scientific Developments in Bioaccumulation Research. Helsinki, September 24.

Sara Al-Marri, Mohamad Al-Sulaiti, F.A.P.C. Gobas and A. Cancelli. 2014. Environmental fate modelling of contaminants in constructed wetlands. Qatar Foundation R&D Annual Research Conference (ARC'14), November, 2014

Gobas, F.A.P.C., S.Z. Cohen, S.M. Haefner. 2014. Bioaccumulation Risk Assessment of Pentachloronitrobenzene II: Lessons Learned. 13th IUPAC International Congress of Pesticide Chemistry. San Francisco, California, USA, August 1-14.

Gobas, F.A.P.C., S.Z. Cohen, S.M. Haefner. 2014. Bioaccumulation Risk Assessment of Pentachloronitrobenzene I: Lessons Learned. 13th IUPAC International Congress of Pesticide Chemistry. San Francisco, California, USA, August 1-14.

Gobas, F.A.P.C. 2014. Use of Activity and Fugacity to increase Weight of Evidence in Bioaccumulation and Risk Assessment of D5. Japan Expert Workshop. Advanced Studies of Environmental Assessment. Tokyo, July 1.

J. Kim, D.E. Powell, K.B. Woodburn, R.M. Seston and F.A.P.C. Gobas. 2014. Estimating and Evaluating Bioaccumulation of Hydrophobic Compounds in the Aquatic Environment Using Linked SimpleTreat+QWASI+AQUAWEB models. 23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Glasgow, Scotland, May 16 – 20.

F.A.P.C. Gobas. 2013. The application of Activity and Fugacity to increase Weight of Evidence in Environmental Risk Assessments. 34th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Nashville, USA, November 17 – 21.

M. Crawford, F.A.P.C. Gobas. 2013. An Empirical Activity and Fugacity-Based Approach to Risk Assessment of Petroleum Hydrocarbons. 34th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Nashville, USA, November 17 – 21.

F.A.P.C. Gobas, L.P. Burkhard, W.J. Doucette, K.G. Sappington, E. Verbruggen, B.K. Hope, M.A. Bonnell, J.A. Arnot, J.V. Tarazona. 2013. Terrestrial Bioaccumulation Models for Bioaccumulation Screening and Exposure Assessment: Workshop Summary. 34th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Nashville, USA, November 17 – 21.

M.R. McDougall, F.A.P.C. Gobas. 2013. A modified bioaccumulation model to evaluate trophic magnification of select perfluoroalkyl acids (PFAAs) in a terrestrial food web. 34th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Nashville, USA, November 17 – 21.

J.C. Lo, G. Allard, G. Saroya, L. Charuaud, C.J. Kennedy, D. Campbell, F.A.P.C. Gobas. 2013. Testing in-vitro to in-vivo fish biotransformation extrapolation methods for very hydrophobic chemicals. 34th Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, Nashville, USA, November 17 – 21.

L. Saunders, F.A.P.C. Gobas. 2013. The effect of pre-exposure on in vitro biotransformation rates of hydrophobic chemicals in rainbow trout (*Oncorhynchus Mykiss*). 40th Aquatic Toxicity Workshop, Moncton, New Brunswick, Canada, October 6-10.

J. Alava, M.G. Ikonou, M. Riofrio, F.A.P.C. Gobas. 2012. Perfluoroalkyl contaminants (PFCs) in environmental matrices collected in the Antarctic Peninsula. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

P. Luk, G. Pelletier, F.A.P.C. Gobas. 2012. Modeling the bioaccumulation of polybrominated diphenyl ethers (PBDEs) in the marine food web of Puget Sound, Washington. 33rd Annual

Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

J. Kim, D.E. Powell, K.B. Woodburn, F.A.P.C. Gobas. 2012. Application of a linked AQWASI + AQUAWEB model for estimating and evaluating bioaccumulation of hydrophobic compounds in aquatic food webs. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

F.A.P.C. Gobas, A.R. Brisebois, H.A. Leslie, P. Leonards. 2012. Relationship between the BCF, BAF, and the TMF. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

F.A.P.C. Gobas, M. McConnell, V. Otton, M.G. Ikonomou. 2012. Bioaccumulation of ionizing mono-phthalate esters in a marine aquatic food-web. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

F.A.P.C. Gobas, J. Arblaster, P. Wing Ho Luk, A. Arnot. 2012. Towards ecologically relevant sediment quality criteria. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

J.P. Benskin, M.G. Ikonomou, F.A.P.C. Gobas, M.B. Woudneh, T. Begley, J.R. Cosgrove. 2012. Are all N-alkyl substituted perfluorooctane sulfonamides PFOS-precursors? The case of SAMPAP diester biodegradation in marine sediments. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

F.A.P.C. Gobas, V. Otton, K. Clark, M.G. Ikonomou. 2012. The case for activity based environmental risk assessment: The example of the plasticizer DEHP. 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

L. Saunders, F.A.P.C. Gobas. 2012. The effect of pre-exposure on in vitro biotransformation rates of hydrophobic chemicals in rainbow trout (*Oncorhynchus Myrkiss*). 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

F.A.P.C. Gobas. 2012. Are PBT evaluation and environmental criteria protecting marine mammals? 33rd Annual Meeting of the Society of Environmental Toxicology and Chemistry in North America, California, USA, November 11 – 15.

E. Powell, F.A.P.C. Gobas, K.A. Kidd, D.C.G. Muir, R.M. Seston, K.B. Woodburn. 2012. Uncertainty of bioaccumulation and biomagnification measurements in natural aquatic food webs: a sensitivity analysis approach. 22nd Annual Meeting of the Society of Environmental Toxicology and Chemistry in Europe, Berlin, Germany, May 20 – 24.

Gobas, F.A.P.C., V. Otton, K. Clark, M.G. Ikonou. 2012. The case for activity and fugacity based environmental risk assessment: The example of the plasticizer DEHP. GeoEnviroLogic 7th Annual Risk Symposium. Vancouver, May 31 & June 1, 2011)

Gobas, F.A.P.C. 2012. Progress Towards the Development and Testing of in-vivo bioaccumulation assessment methods for Metabolizing Substances. Health and Environmental Sciences Institute (HESI) In Vivo Experts Workshop. Berlin. Germany. May 17-18, 2012.

Gobas, F.A.P.C., Arblaster, J., Alava, J.J. 2012. Towards ecosystem based sediment quality criteria. 2012 Pacific North West Regional Conference of the Society of Environmental Toxicology and Chemistry, Vancouver, April 26-28.

F.A.P.C. Gobas, J. Arblaster, M.G. Ikonou. 2012. Webinar: Towards developing ecosystem based sediment quality guidelines for PCBs & related contaminants. February 15. 33 participants.

J. Arblaster, F.A.Gobas, M.G. Ikonou. 2011. Sediment Quality Guidelines in British Columbia, Canada. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

F.A. Gobas, A.R. Brisebois, H.A. Leslie, P. Leonards. 2011. Relationship Between the BCF, BAF and the TMF. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

D. Mackay, F. Gobas, J. Arnot. 2011. Exploiting Relationships Between Metrics of Biouptake in Fish to Improve Laboratory to Field Extrapolation. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

G.Zandpoor, H. Lai, M.G. Ikonou, F.A. Gobas. 2011. Development and Evaluation of a Multimedia Environmental Fate Model for Phthalate Esters in the False Creek, British Columbia. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

J.J. Alava, F.A. Gobas. 2011. Modeling the Bioaccumulation Potential of Cesium 137 in a Marine Food Web of the Northwest Pacific, Canada. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

G.Zandpour, H. Lai, M.G. Ikonou, F.A. Gobas. 2011. Development and Evaluation of a Multimedia Environmental Fate Model for Phthalate Esters in a Marine Aquatic Food Web. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

J.P. Benskin, M. Ikonou, F.A. Gobas. 2011. Bioaccumulation Modeling of Perfluorinated Compounds in an Aquatic Food Web. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

J. Lo, C.J. Kennedy, S.V. Otton, M.M. Moore, F.A. Gobas. 2011. A Protocol for Measuring In Vivo Biotransformation Rates of Hydrophobic Substances in Fish. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

D.E. Powell, Dow Corning, F.A. Gobas, K. Kidd, D. Muir. 2011. A Sensitivity Analysis Approach to Bioaccumulation and Biomagnification in Aquatic Food Webs. 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

P. Leonards, S.V. Leeuwen, B.v. Hattum, F. Gobas, H. Leslie. 2011. Laboratory Biotransformation – A Link in Understanding Field Bioaccumulation? 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Boston, November 12 – 17.

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**ATTACHMENT C: SPOKANE RIVER PCB CONCENTRATION DATA
ANALYSIS: TECHNICAL MEMORANDUM BY AZIMUTH**

Technical Memorandum

Spokane River PCB Concentration Data Analysis

Date: October 9, 2019

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Appendix A: Maps, Figures, and Tables showing PCB Concentration Data (Includes Electronic Files)



USE & LIMITATIONS OF THIS MEMORANDUM

This technical memorandum has been prepared by Azimuth Consulting Group Partnership ("Azimuth") for the use of Baron & Budd, P.C. (Baron & Budd P.C.; the "Client") and Expert(s) retained by the Client, in particular Dr. Frank Gobas. The Client and Expert(s) have been party to the development of the scope of work for the subject project and understand its limitations.

The Client agrees, by accepting this memorandum, that in providing this memorandum and performing the services in preparation of this memorandum Azimuth accepts no responsibility in respect of the Spokane River study area described in this memorandum or for any business or legal decisions made by the Client in reliance on this memorandum.

This memorandum is intended to document the methods used by Azimuth to summarize and analyze data on polychlorinated biphenyl (PCB) concentrations in environmental media from the Spokane River. Summary tables, figures and maps are provided as an electronic appendix to this memorandum for the use of the Client and Experts. Basic data interpretation is provided; conclusions and recommendations with respect to PCBs in the Spokane River are not contained herein.

Any use of, reliance on, or decision made by a third party based on this memorandum (other than Baron & Budd and its experts engaged for the purposes of the Action related to Baron & Budd's representation of entities with regards to PCB contamination in the Spokane River), or the services performed by Azimuth in preparation of this memorandum is expressly prohibited, without prior written authorization from Azimuth. Without such prior written authorization, Azimuth accepts no liability or responsibility for any loss, damage, or liability of any kind that may be suffered or incurred by any third party as a result of that third party's use of, reliance on, or any decision made based on this memorandum or the services performed by Azimuth in preparation of this memorandum.

The information contained in this memorandum is based, in part, upon information provided by others (i.e., a project database provided by other parties retained by Baron & Budd). While Azimuth has reviewed some of the data contained in the database for accuracy, in preparing this memorandum, Azimuth has assumed that the data or other information provided by others is factual and accurate. If any of the information is inaccurate, conditions of the study area change, new information is discovered, and/or unexpected conditions are encountered in future work, then modifications by Azimuth to the information reported in this memorandum may be necessary.

This memorandum is time-sensitive and pertains to a specific study area, project and scope of work. It is not applicable to any other study areas, other than that to which it specifically refers.

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ACRONYM LIST

DOC – Dissolved organic carbon

Ecology – Washington State’s Department of Ecology

EIM – Ecology’s Environmental Information Management System database

FOIA – Freedom of Information Act

LSS – Largescale Sucker

MWF – Mountain Whitefish

PARIS – Washington State’s Permitting and Reporting Information System

PCB – Polychlorinated biphenyl

PGG – Pacific Groundwater Group

RBT – Rainbow Trout

RM – River Mile

SRRTTF – Spokane River Regional Toxics Task Force

tPCB – Total polychlorinated biphenyl

TDS – Total dissolved solids

TOC – Total organic carbon

tPCBs – Total polychlorinated biphenyls

TS – Total solids

TSS – Total suspended solids

QAQC – Quality assurance/quality control



1. OVERVIEW

This memorandum documents the methods used to summarize and analyze Spokane River data on polychlorinated biphenyl (PCB) concentrations in aquatic receptors, including fish and crayfish ("fish"), biofilm/periphyton and invertebrates, as well as in sediments, suspended sediments and surface water.

A project database was received from Baron & Budd P.C. ("Baron & Budd"; the "Client") and served as the basis for this data summary and analysis. The data analysis was supported by a literature review, which focused on publications by the Washington State Department of Ecology ("Ecology"), LimnoTech for the Spokane River Regional Toxics Task Force (SRRTTF), the City of Spokane, as well as other relevant documents and information. The literature review was used to identify original reports relevant to the Spokane River PCB data analysis.

Steps involved in the analysis included data clean-up and filtering, data treatment and transformations, calculations and analysis, including preparation of summary tables, figures and maps, and quality assurance/quality control (QAQC) review. These steps are described in more detail in the following sections of this memorandum:

1. Overview
2. Source Database
3. Dataset Preparation
4. Calculations & Analysis
5. References

This memorandum specifically supports the bioaccumulation model Expert Report by Dr. Frank Gobas. Various analyses were completed at the request of the Expert and were provided as options for use in the Expert Report. Summaries of the data (tables, select figures and maps) using various approaches are provided in [Appendix A](#) (electronic file) of this memorandum.



2. SOURCE DATABASE

2.1. Description

A database containing PCB concentration data in various media collected from the Spokane River (e.g., surface water, effluent, sediment, suspended sediment and biota tissues) was received from Baron & Budd for the project. The database was prepared by Baron & Budd's consultants, Pacific Groundwater Group (PGG). Original data were imported into the project database from various sources, including:

- Washington State's Department of Ecology (Ecology) Environmental Information Management System (EIM) database;
- City of Spokane database;
- Washington State's Permitting and Reporting Information System (PARIS) database;
- Freedom of Information Act (FOIA) requests;
- Direct imports of data files from various sources, including: City of Spokane data, SRRTTF data, and data entered from original reports.

Two versions of the database were used for the analysis:

- Version 13 (April 04, 2019) was complete for fish tissue data and suspended sediments and used for final analysis of these datasets (PGG 2019a).
- Version 18 (June 11, 2019) contained updates to the surface water dataset and newly-released 2018 Ecology data (Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c). This version was used for final analysis of biofilm, invertebrate, sediment, and surface water data (PGG 2019b).

The database was delivered in two file formats:

- Microsoft Access® – The Access database contained PCB concentration data imported into several tables with various fields of information (e.g., study and location information). Data tables in Access were reviewed as needed, but were not directly used in the analysis.
- Export Query – Selected fields were exported from Access into a comma-separated value (csv) file that was used directly in the data analysis. For version 18, Azimuth exported the Export Query directly from Access.

A description of the fields contained in the Export Query is shown in [Table 2-1](#) (modified from PGG).



**Table 2-1: Fields and descriptions contained in the Spokane River PCB project database
Export Query file.**

Field	Definition
StudyID	Department of Ecology (or other entity) study ID code
txtStationID	Name of sample collection location
Location	Secondary location name/description
River	River sample was collected from; used if sample was collected in or adjacent to a river
RiverMile	River mile of location sample was collected from
Latitude	Location coordinates - latitude
Longitude	Location coordinates - longitude
txtSampleID	Name of sample, may be assigned by sampler or lab
dtmSampleDate	Date sample collected on
CollectionMethod	Method used for collecting sample
UpperDepth	Upper depth of soil/sediment sample
LowerDepth	Lower depth of soil/sediment sample
DepthUnit	Depth unit of soil/sediment sample
TaxonName	Scientific name of species or taxon (e.g., family) for tissue samples
CompositeFlag	Flagged "y" if sample is a composite of multiple samples (e.g., individual fish, multiple sediment grabs); "n" if not
Data Source	Entity providing data (e.g., City of Spokane)
ResultTaxonName	Taxon if broken out by result (not filled in)
TissueType	Tissue type of fish analyzed for PCB or other parameter (e.g., whole organism; fillet, skin on)
AnalysisMethod	Method of chemical analysis used by laboratory
Matrix	General media type (e.g., water, sediment, tissue)
Sample Source	Sub-category of media type (e.g., cap sand, freshwater sediment, effluent, groundwater)
LabReplicateFlag	A replicate sample split in the laboratory
SampleReplicateFlag	Separate samples collected as close as possible to the same point in space and time as the originals. In the case of tissues, is from the same fish/composite group as the original.
FractionAnalyzed	Total or dissolved fraction for water samples
QAFlag	Flag for blank, duplicate, spike samples (generally not filled in)
Result_Basis	Whether concentration is on a wet weight or dry weight basis
Constituent	Analyte (e.g., PCB constituent or supporting measurement)
dblLimit	Detection limit
Result	Value (i.e., concentration)
txtUnits	Units of measure for result



Field	Definition
txtQual	Qualifier (e.g., identifies results that are "U" = less than detection limit or "J" = estimated)
CountOfAnalyses	Number of analytes in Project Summed Constituents (e.g., number of congeners or Aroclors summed for total PCBs)
CountOfNDs	Number of non-detect values in Project Summed Constituents
dblBlankResult	Concentration of constituent in blank sample (water data and v13 only)
txtResult>3xBlankFlag	"Yes" if PCB sample measurement is above the blank; "no" if not (water data and v13 only)
txtBlankCensorNote	Note added by PGG regarding blank censoring (water data and v13 only)

2.2. PCB Parameters

2.2.1. Summation of Total PCBs (tPCBs)

PCBs consist of 209 closely related compounds, referred to as congeners, and were produced as commercial mixtures called Aroclors. PCB measured parameters provided in the database include individual PCB Aroclors and individual PCB congeners. As well, total PCB (tPCB) concentrations (C_{tPCB}) were calculated in the database as the sum of all individual PCB Aroclors or PCB congeners/co-eluters ($C_{PCB(n)}$) measured in a sample ([Equation 1](#)):

Equation 1: Summation of individual PCB parameters for tPCB result, shown for PCB congeners.

$$C_{tPCB (congeners)} = \sum_{n=1}^{209} C_{PCB(n)}$$

The number of PCB congeners or Aroclors measured in a sample can vary between studies. However, most analytical laboratories attempt to include all the PCB congeners in the analysis that contribute significantly to the total concentration of PCBs.

Three approaches were used in the database to determine tPCBs. Each approach uses a different assumption for the concentration individual congeners or individual Aroclors that were measured below the analytical detection limit¹ (also referred to as "non-detects"). PCB results that are less than the

¹ The Access database has a "LimitType" field which identifies the type of detection limit reported. Some of the main categories of detection limits include (see EIM database reference material [Ecology, 2018]):



detection limit are denoted in the database with a "U" flag (including U variants such as U, UG, UJ, NUJ) in the field "txtQual". Some of the key data qualifier flags are shown in **Table 2-2**, with a more complete list for the EIM database provided in EIM reference materials (Ecology 2018), as well as in original reports.

Table 2-2: Data qualifier flags⁵ contained in the database.

Flag	Definition
B	"Blank detection" - Analyte detected in sample and method blank. Reported result is sample concentration without blank correction or associated quantitation limit.
E	"Exceeds" - The concentration exceeds the known calibration range.
J	"Estimated" - The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
N	"Tentative" - There is evidence the analyte is present in this sample; tentatively identified analyte.
NJ	"Tentative Estimate" - The analyte has been tentatively identified and the associated numerical value represents its approximate concentration.
NUJ	"Undetected at Estimated Limit for Tentative Analyte" - There is evidence the analyte is present in the sample. Tentatively identified analyte was not detected at or above the reported estimate.
REJ*	"Unusable" - The data are unusable for all purposes. Sample results for the analyte are rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.

- MRL - Method Reporting Limit
- PQL - Practical Quantitation Limit
- EQL - Estimated Quantitation Limit
- LOQ - Limit of Quantitation
- SQL - Sample Quantitation Limit



Flag	Definition
U	"Undetected" - The analyte was not detected at or above the reported sample quantitation limit.
UJ	"Undetected at Estimated Limit" – The analyte was not detected at or above the reported sample quantitation limit. However, the reported quantitation limit is approximate.

Table 2-2 Notes:

[§]References used include (Serdar and Johnson 2006, Era-Miller 2015b, Ecology 2018).

*There were no REJ flags in tissue or sediment datasets, but there were a small number of these flags in the 2000 (Golding 2001) and 2003 (Serdar, Lubliner et al. 2011) surface water data; these were treated the same as "U" qualifiers in the summation of total PCBs.

The three approaches for calculating tPCBs were:

1. "Zero" (tPCB Congeners/Aroclors – LimitZero): Individual congeners or Aroclors that were less than the detection limit were assigned zero in the summation of tPCBs.
2. "Half" (tPCB Congeners/Aroclors - Limit/2): Individual congeners or Aroclors that were less than the detection limit were assigned one-half the detection limit in the summation of tPCBs.
3. "Full" (tPCB Congeners/Aroclors – Limit): Individual congeners or Aroclors that were less than the detection limit were assigned the full detection limit in the summation of tPCBs.

All three of these methods are considered common approaches to calculate tPCBs from individual congener or Aroclor measurements and provide a range of uncertainty in the estimate of tPCB concentrations. We note that there were some cases where all PCB constituents measured in a sample were less than the analytical detection limit, yielding tPCB less than the detection limit. This occurred primarily with data analyzed by Aroclor methods and corresponded to a relatively small proportion of the tissue and sediment data, but much of the 2000 surface water Aroclor data. For congener analysis, there were three surface water samples (2003 and 2012) in which all PCB congeners were less than detection limit; all other congener data for water, sediment and tissue had tPCB results above detection limit.

2.2.2. 3x Blank Censored tPCBs for Surface Water

The same three substitution approaches for non-detect parameters, as explained in [Section 2.2.1](#) above, were used in the summation of tPCBs for surface water data. However, for surface water, concentrations of individual PCB congeners in each field sample were screened against three times the concentration of the congener in the method blank "3xblank", in addition to the standard analytical detection limit screening. This was done for water samples because the concentration of PCBs in water is generally low relative to background contamination levels that may be introduced during sampling and



analysis. Method blanks are described in LimnoTech's Quality Assurance Project Plan for a SRRTTF study: *A method blank is an analyte-free matrix, analyzed as a normal sample by the laboratory using normal sample preparation and analytical procedures. A method blank is used for monitoring and documenting bias due to background contamination in the analytical environment.* (LimnoTech 2014). The 3xblank censoring approach is also consistent with the most recent and comprehensive measurements of PCBs in water of the Spokane River, collected by LimnoTech on behalf of SRRTTF.

The three approaches for determining tPCBs in water samples applied the same three assumptions for the concentrations of PCB congeners in water samples that were less than 3x the concentration in the method blank:

1. "Zero" (tPCB Congeners/Aroclors 3xBlank Censored – LimitZero): Individual congeners or Aroclors in water samples that were measured below 3xblank were assigned zero in the summation of tPCBs.
2. "Half" (tPCB Congeners/Aroclors 3xBlank Censored – Limit/2): Individual congeners or Aroclors in water samples that were measured below 3xblank were assigned one-half the analytical detection limit in the summation of tPCBs.
3. "Full" (tPCB Congeners/Aroclors 3xBlank Censored – Limit): Individual congeners or Aroclors in water samples that were measured below 3xblank were assigned the full analytical detection limit in the summation of tPCBs.

This approach is referred to as blank censoring, and does not include blank correction/subtraction. Blank correction/subtraction is where the PCB concentration in a blank sample (or multiple blanks) is subtracted from the PCB concentration in a field sample. (LimnoTech 2015) assessed uncertainty in the 3xblank censoring method by comparing the censored results to those obtained by subtracting the maximum congener concentration in the blank from the field result (i.e., blank correction/subtraction). For tPCB less than 200 pg/L, the 3xblank censored results were, on average, 20% higher than those using the blank correction/subtraction method. For tPCB greater than 200 pg/L, 3xblank censoring and blank correction/subtraction methods were virtually equivalent.

2.3. Review of Database

2.3.1. General

Quality assurance/quality control (QA/QC) review of the data contained in the project database was conducted on all database versions. After reviews of earlier versions, information was added to the database to support data analysis (e.g., supporting parameters added; the spatial coverage was expanded to include data throughout the entire Spokane River; and the fields "River" and "RiverMile" were added to spatially locate samples in the Spokane River based on latitude and longitude entries for sample stations). The database was cross-checked with data reported in original studies for accuracy and completeness by Azimuth (e.g., tPCB Congeners/Aroclors – LimitZero were spot-checked with tPCBs



reported in Ecology studies; ancillary data was checked for entry and completeness in the database; tPCBs were recalculated for a few samples; other information such as species, tissue types, sample depths and location details were checked). All issues identified with the data were corrected.

2.3.2. Fish Tissue and Biofilm

All PCB tissue concentration data were in units of ng/kg wet weight. Lipid contents (%) were measured for the majority of fish, invertebrate and biofilm samples and were used in lipid-normalizations described in this document. Total organic carbon contents (TOC, %) were measured in biofilm samples and used for TOC-normalizations. Other fish tissue supporting data (e.g., fish weight and length) were retained in the database but were not used in the analysis.

For the tissue dataset, two changes were made to the project database, related to errors or omissions in the original EIM database (identified by cross-checks against Ecology reports):

- For study AJOH0005, two Largescale Sucker (*Catostomus macrocheilus*) fish samples that were collected from the Spokane River in Idaho were added to the database for completeness (Sample IDs: 94328435 and 93318244; data transcribed into Excel by Azimuth).
- For study AJOH0022 and sample ID 99485018, an incorrect taxon name was entered into EIM for the Aroclor results only (not congener results); *Oncorhynchus mykiss* was corrected to *Catostomus macrocheilus*.

Azimuth made two other corrections to the tissue dataset during analysis:

- The tissue type of crayfish sample 94318265 in study AJOH0005 was designated "Whole organism (animal)" in the EIM database. This appeared erroneous as all other samples collected during the program were designated as "Muscle" in EIM and crayfish samples were designated by Ecology as "Muscle" or "Fillet" in their reports (Davis and Serdar 1994, Johnson 1994a, Ecology 1995). The tissue type for this sample was therefore changed to "Muscle" in the analysis code (see also [Section 3](#)).

Other tissue types were re-labelled in the analysis code to keep naming conventions consistent between studies (see [Section 3](#)).

- The biofilm sample L30061-12 from location SR3A had four congeners (PCB-174, -180/193, and -187) reported as a separate sample - L30061-12 W. These four congeners from 12 W were added to the tPCB results for sample 12 for all three limit types. "Count of Analyses" was also corrected for this sample.

2.3.3. Sediment

All PCB sediment concentration data were in units of ng/kg dry weight. TOC contents (%) were measured in most samples and used for TOC-normalizations, which were also provided. Total solids (TS, %) were measured in some samples and were summarized.



For sediment data, some changes were made to the project database, related to issues with the data imported from the EIM database. These issues were identified during a review of Ecology reports:

- A few studies were removed from the database to avoid duplication of data in the project database. These studies (Study ID) include:
 - SPOK2000 was removed because it duplicated AJOH0019 sediment PCB data (Johnson and Norton 2001).
 - FWSPOR00 is also the same study as AJOH0019 and was removed to avoid confusion although it only had toxicity test results.
 - SPOK9394 was a duplicate of AJOH0005 (Ecology 1995) for sediment chemistry data, except for sample IDs 318236, 318273, 328406, and 328408, which were included in SPOK9394 but not AJOH0005. All other SPOK9394 data were removed.
 - SPOKNR94 was a duplicate of DBAT0001 (Batts and Johnson 1995) for sediment chemistry data so it was removed.
 - TENLAK92 is the same study as DSER0002 (Serdar, Johnson et al. 1994). Although TENLAK92 only had metals and TOC data for sediments (no PCBs), it was removed from the database.
- Sediment data collected by Ecology in 2008 and 2010 for the Upriver Dam 5-year review (Ecology 2015) were not included in EIM and were added to the project database.

Azimuth made a few corrections and revisions during data analysis:

- tPCB values for all three detection limit treatments were corrected for DBAT001. Based on how data were entered in EIM, individual Aroclor analytes were recognized as single samples. Azimuth summed the individual Aroclor results by Station ID to correct the sediment concentrations (Batts and Johnson 1995).
- For study UPRVRDAM, minor edits were made to match data reported in (Anchor Environmental LLC 2005). Sample IDs AN-61SD-A, AN-81SD-A, and UPR103041007 had Sample Replicate Flags changed from "N" to "Y". As well for this study, Upper Depth was changed to 0, Lower Depth to 10 and Depth Unit to cm.
- For SRUW-Spokane (Fernandez 2012, Borgias and Hamlin 2017, PGG 2019b), Sample IDs 1308073-01REX, 1308073-03REX, and 1308073-06REX had Sample Replicate Flags changed from "N" to "Y", and Sample IDs 1308073-06 and 438026 had Sample Replicate Flags changed from "Y" to "N".
- For consistency, all sediment upper and lower depth units were converted from original units (of inches, feet, meters and centimeters) to centimeters.



- Removed TOC sediment duplicates from the dataset, including any Sample IDs in study AJOH0019 with analysis method "PSEP-TOC" and Sample IDs 3454111, 3454112 and 3454113 in the study DSER0010 with analysis method "PSEP-TOC".

2.3.4. Suspended Sediment

PCB concentrations in suspended sediments were reported in units of ng/kg dry weight. TOC contents (%) were used to normalize tPCB concentrations. Total solids (TS, %) and moisture (%) were measured in some samples and were summarized.

Azimuth entered TOC and total solids data from study BERA0012 (Era-Miller and McCall 2017) and BERA0009 (Era-Miller 2014a) from study reports that had not been entered into EIM. There were no other corrections made to the suspended sediment dataset.

2.3.5. Surface Water

PCB surface water concentration data were in units of ng/L. Ancillary parameters (dissolved organic carbon [DOC], TOC, total suspended solids [TSS], and total dissolved solids [TDS]), all in units of mg/L, were retained and summarized. Water data were not normalized to ancillary parameters.

Water data in the database were reviewed with corrections and updates being made to the 3xblank censored tPCB parameters and filling in fields (e.g., sample source and station/location information). This was mostly needed for some of the SRRTTF studies that were imported directly from data files (not from EIM).

Azimuth made various edits to the water dataset during data analysis:

- Some samples from study SRRTTF-2014 (LimnoTech 2015), corresponding to blanks, were removed from the surface water dataset (e.g., WG47451-102 (A) and similar Sample IDs).
- Certain samples from study Combined Idaho Data (PGG 2019b) were removed. Some were high volume samples that had equipment contamination issues (e.g., L21904-x and L21905-x); others were only partially reported samples (i.e., L21917-9 W and L21910-18 W) that were fully reported in SRRTTF (2014).
- Study VCEA0318 (PGG 2019b) (one sample originally from EIM database) was removed as the actual location was unknown (unclear if in-river and no report was found to investigate) and the detection limits were very high, with all parameters less than the detection limit.
- Missing field (e.g., location) information was filled in for a few cases.
- Several studies used different sample IDs for tPCB versus ancillary data. Based on a review of reports or datasets, the ancillary data were assigned to sample IDs used for tPCB, to avoid removing the ancillary data (see [Section 3](#)). This was applied to:
 - Two samples from study BERA0012 (Era-Miller and McCall 2017) (1602016-10 was relabeled as 1602016-13, and 1602016-11 was relabeled as 1602016-14).



- All ancillary data from SRRTTF datasets for 2014, 2015 and 2016 (LimnoTech 2015, LimnoTech 2016b, LimnoTech 2017) were assigned to tPCB Sample IDs by matching sample stations, dates and times.
- Four samples from WHOB003 (Hobbs, McCall et al. 2019) (sample ID 1606035-11 was changed to 1606035-18, 1606035-12 to 1606035-19, 1702027-02 to 1702027-24, and 1702027-03 to 1702027-25).
- Composite flags "Y" were assigned to several samples:
 - Combined Idaho Data (PGG 2019b): Sample IDs L21877-83 and L21877-85.
 - SRRTTF-2018 (LimnoTech 2019): Sample IDs L29884-2, L29884-3, L29884-4, L29884-5, L29884-6, L29884-7, L29884-8, L29884-9, L29884-10, and L29884-11.



3. DATASET PREPARATION

R statistical computing software version 3.5.1 (2018-07-02) - "Feather Spray" was used for the data analysis. An R script (programming code) was developed in R Markdown (rmd) format and run in R Studio. Several steps were conducted in R, described in the subsections below.

3.1. Initial Preparation

The work space was cleared and set-up for data analysis. These steps included:

1. Clearing workspace of any previously loaded objects,
2. Setting the working directory – directing the software to the folder containing source files necessary for the code to run properly, including the R scripts and data,
3. Installing and loading software packages (designed to accomplish various analytical tasks in R) required for the data analysis. Packages used for this project include:
 - tidyverse (data wrangling and organization, includes ggplot for creating graphs),
 - lubridate (working with dates),
 - knitr (converting rmd script to PDF),
 - evaluate (parsing and evaluating tools),
 - ggmap (creating maps),
 - ggrepel (keeping text labels away from each other),
 - broom (creating tidy tables),
 - lme4 (linear mixed-effects regression models), and
 - lmerTest (linear mixed-effects models to evaluate significance of results).
4. Imported data files – loaded the Export Query file.
5. Formatted variable columns – reviewed import files to ensure that the data were in the proper format. Examples of this include:
 - a) Reformatted dates to be consistent between studies,
 - b) Used lower case formatting for data entries (e.g., "TISSUE", "Tissue", and "tissue" were all changed to "tissue"),
 - c) Inspected variable classes and set these to the correct format (e.g., character, numeric, logical).



3.2. Selecting Datasets

Datasets were subset to a particular media by selecting relevant fields and samples. Data were filtered for several conditions:

1. Type of media:
 - a. Fish tissue data were subset to Matrix = Tissue, Sample Source = Animal Tissue.
 - b. Biofilm/periphyton tissue data were subset to Matrix = Tissue, Sample Source = Biofilm.
 - c. Invertebrate tissue data were subset to Matrix = Tissue, Sample Source = Invertebrate.
 - d. Sediment data were selected from the database using the following criteria:
 - i. Matrix = Solid/Sediment, Sample Source = Sediment, Freshwater Sediment, "null/blank"; these groups were all relabeled as Sample Source = Freshwater Sediment.
 - ii. Matrix = Sediment, Sample Source = Freshwater Sediment; these data from SWON0001 were included with the above sediment samples.
 - iii. Matrix = Solid/Sediment, Sample Source = Cap Sand. This group was retained but kept separate (represents sampling of cap sand upper layer after Upriver Dam remediation).
 - e. Suspended sediment samples were selected using Matrix = Solid/Sediment, Sample Source = Fresh/Surface Water, and were renamed Suspended Sediment.
 - f. Surface water samples were identified as Matrix = Water, Sample Source = Fresh/Surface Water.
2. Data collected from within the Spokane River itself, excluding tributaries (e.g., River = Spokane River).
3. Removed studies containing ancillary parameters only (e.g., lipids, TOC, TSS, etc.) without paired PCB data. These data were generally from studies on other contaminants, such as mercury, in the Spokane River.
4. Carried forward constituents that were used or summarized in the analysis:
 - a. tPCB results (based on Aroclors, congeners, and including the 3x blank-censored tPCBs for the surface water using the full limit, half limit, zero detection limit treatments);
 - b. Ancillary data for samples with paired PCB data were retained:



- i. Fish, invertebrates and biofilm – lipid contents²; fish length and weight were retained but not used in the analysis;
 - ii. Biofilm – TOC contents (in addition to lipid content);
 - iii. Sediment – TOC contents, and total solids;
 - iv. Suspended sediments – TOC;
 - v. Surface water – TSS, TDS, TOC, and DOC.
5. Removed unnecessary columns to limit dataset to media-specific information (e.g., for tissue analysis removed CollectionMethod, UpperDepth, LowerDepth, and FractionAnalyzed; for sediment analysis removed TaxonName, ResultTaxonName, TissueType, LabReplicateFlag, FractionAnalyzed, and QAFlag).

Based on these selection criteria, the full list of studies containing PCB concentration data in the Spokane River are shown in a series of tables below:

- **Table 3-1** – fish, biofilm and invertebrates,
- **Table 3-2** – sediment,
- **Table 3-3**– suspended sediment, and
- **Table 3-4** – surface water.

These lists correspond to studies identified as having relevant data in the literature review.

² “Non-polar lipids” were removed as a constituent because there were only two samples and both had standard lipid data.



Table 3-1: Tissue study IDs[¶], years sampled, references included in the Spokane River fish, biofilm and invertebrate tissue dataset. Fish studies included in the baseline (2001-2005), intermediary (2012) or current[§] (2014-2018) time period scenarios and those included in the temporal trend analysis "Y" are indicated.

Tissue Study ID	Year Sampled	Reference(s)	Time Period Scenario	Temporal Trends Analysis
DSER0002	1992	(Serdar, Johnson et al. 1994)	-	Y
AJOH0005	1993	(Davis and Serdar 1994, Ecology 1995)	-	Y
AJOH0005	1994	(Johnson 1994a, Ecology 1995)	-	Y
WSPMP93T	1993	(Davis, Johnson et al. 1995)	-	Y
AJOH0008	1996	(Johnson 1997)	-	Y
AJOH0022	1999	(Johnson 2000)	-	Y
RJAC002	2001	(Jack and Roose 2002)	Baseline	Y
DSER0010	2003	(Serdar, Lubliner et al. 2011)	Baseline	Y
DSER0010	2004	(Serdar, Lubliner et al. 2011)	Baseline	Y
WSTMP03T	2003	(Serdar, Lubliner et al. 2011)	Baseline	Y
DSER0016	2005	(Serdar and Johnson 2006)	Baseline	Y
WSTMP12	2012	(Seiders, Deligeannis et al. 2014)	2012	Y
BERA0011	2014	(Era-Miller 2015a)	Current	-
MIFR0003 [§]	2016	(Wong 2018)	-	-
SWON0001*	2018	(Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c)	N/A	N/A

[¶] Washington Department of Ecology/U.S. EPA studies (Joy 1984) and (Johnson 1994b) were not entered by Ecology into the EIM database and were, therefore, not included in this analysis. These studies are older and not representative of baseline or current conditions.

[§] See Expert Report for further information on concentrations of PCBs in fish for the current period.

[§] MIFR0003 collected 1 year old Rainbow Trout from Lake Spokane 4 months after hatchery release. These trout were not included in the current dataset because they were younger and smaller than those collected in earlier studies.



* SWON0001 collected samples of biofilm and invertebrates, which are presented separately from fish tissue data.

Table 3-2: Sediment study IDs, years sampled and references included in the Spokane River bedded sediment dataset. Sediment studies included in the baseline (2003-2004) or current (2013-2018) time period scenarios are indicated in the table.

Sediment Study ID	Year Sampled	Reference	Time Period Scenario
BHOP0001	1990	(Hopkins 1991)	-
DSER0002	1992	(Serdar, Johnson et al. 1994)	-
AJOH0005	1993	(Ecology 1995)	-
AJOH0005	1994	(Ecology 1995)	-
SPOK9394	1993	(Ecology 1995)	-
SPOK9394	1994	(Ecology 1995)	-
DBAT0001	1994	(Batts and Johnson 1995)	-
AJOH0019	2000	(Johnson and Norton 2001)	-
DSER0010	2003	(Serdar, Lubliner et al. 2011)	Baseline
DSER0010	2004	(Serdar, Lubliner et al. 2011)	Baseline
UPRVRDAM	2003	(Anchor Environmental LLC 2005)	Baseline
UPRVRDAM	2004	(Anchor Environmental LLC 2005)	Baseline
UPRDAM2008	2008	(Ecology 2015)	-
2010 UPRIVER DAM MONITORING	2010	(Ecology 2015)	-
SRUW-SPOKANE*	2013	(Fernandez 2012, Borgias and Hamlin 2017, PGG 2019b)	Current
CITYOFSPOKANEWW	2015	(PGG 2019b)	Current
SEDCORE16	2016	(Mathieu 2018)	Current
SWON0001	2018	(Wong and Era-Miller 2019a, Wong and Era-Miller 2019b, Wong and Era-Miller 2019c)	Current

*From project database; earlier (non-sediment) data reported and Quality Assurance Project Plan available.



Table 3-3: Suspended sediment study IDs, years sampled and references included in the Spokane River suspended sediment dataset.

Suspended Sediment Study ID	Year Sampled	Reference
DSER0010	2003	(Serdar, Lubliner et al. 2011)
DSER0010	2004	(Serdar, Lubliner et al. 2011)
BERA0009	2012	(Era-Miller 2014a)
BERA0009	2013	(Era-Miller 2014a)
BERA0012	2015	(Era-Miller and McCall 2017)
BERA0012	2016	(Era-Miller and McCall 2017)
WHOB003	2016	(Hobbs, McCall et al. 2019)
WHOB003	2017	(Hobbs, McCall et al. 2019)

Table 3-4: Surface water study IDs, years sampled and references included in the Spokane River surface water dataset. Surface water studies included in the baseline (2000-2003) or current (2016-2018) time period scenarios are indicated in the table.

Surface Water Study ID	Year Sampled	Reference	Time Period Scenario
SGOL001	2000	(Golding 2001)	Baseline
DSER0010	2003	(Serdar, Lubliner et al. 2011)	Baseline
BERA0009	2012	(Era-Miller 2014a)	-
BERA0009	2013	(Era-Miller 2014a)	-
BERA0012	2016	(Era-Miller and McCall 2017)	-
COMBINED IDAHO DATA	2014	(PGG 2019b)	-
COMBINED IDAHO DATA	2016	(PGG 2019b)	Current (some stations)
SRRTTF-2014	2014	(LimnoTech 2015)	-
SRRTTF-2015	2015	(LimnoTech 2016b)	-
SRRTTF-2016	2016	(LimnoTech 2017)	-
WHOB003	2016	(Hobbs, McCall et al. 2019)	-
WHOB003	2017	(Hobbs, McCall et al. 2019)	Current
SRRTTF-2018	2018	(LimnoTech 2019)	Current



3.3. Dataset Clean-up

Additional steps were taken to clean-up the dataset and ensure data quality and consistency. These included:

1. Removing sample duplicates – additional data filtering was required to ensure samples were not double counted in the dataset:
 - a. Sample replicates were removed from the analysis (corresponding to Sample Replicate Flag = Y), to avoid double counting these samples.
 - b. Similarly, composite surface water samples from SRRTTF water studies (i.e., Combined Idaho Data, SRRTTF-2014, SRRTTF-2015, and SRRTTF-2018) were removed from the dataset. These samples were a mixture of multiple grab samples that had been included in the dataset.
2. Selecting data for samples analyzed by both Aroclor and congener methods – For samples where both congeners and Aroclors were measured, code was added to preferentially select congener data over Aroclor (i.e., tPCB Aroclor was removed in these cases), so that single samples would not be double counted in the statistical summaries. Exceptions to this approach were made for studies³ in which only a limited number of congeners were analyzed; in these cases tPCB Aroclor was selected over tPCB congener. As a result, tPCB congeners were selected over tPCB Aroclors for 60 fish samples from three studies analyzed in duplicate.
3. Cleaning-up tissue type designations and samples with multiple tissues analyzed – Within the tissue dataset, multiple fish tissue types were used for PCB analysis, varying by species of fish/crayfish and by study (e.g., fillet, skin on; fillet, skin off; whole organism (animal)). All categories were reviewed to determine how to best group the data, with emphasis on characterizing the less common tissue types (e.g., whole organism, not fillets). As a result, certain tissue types were removed; others were corrected or relabeled. As well, it was noted that, in some cases, multiple tissue types were analyzed for the same fish or composite sample; these were cleaned-up in the data analysis to ensure that the same fish/composite was not double counted in the summary statistics. The following summarizes the main “tissue type” changes that were made in the dataset (see also [Table 3-5](#)):
 - a. Tissue type “gut contents” was removed.

³ In study AJOH0022 (1999 fish data), only 23 congeners were analyzed, and therefore the tPCB concentration by congener analysis was much lower than tPCB by Aroclor analysis and is considered an underestimate of tPCBs. Thus, tPCB Aroclor results were retained and tPCB congener results were removed for this study.

Similarly, study SGOL001 (2000 water data) analyzed Aroclors and only 19 congeners; therefore tPCB Aroclor results were retained and tPCB congener results were removed.



- b. There were multiple tissue types analyzed for the same fish/composite sample in a few cases in studies DSER0016 and WSTMP12. The "Whole organism, not fillets" (equivalent to carcass) samples were removed, with "Fillet, skin on" or "Whole organism (animal)" being retained, depending on fish species and study (see notes at bottom of [Table 3-5](#)).
- c. Tissue types were re-labeled to use consistent naming conventions and enable proper grouping of data. All changes were based on a review of the original studies and are described in [Table 3-5](#).
- d. Based on corrections and relabeling, the following tissue types were included in the final tissue dataset:
 - Fillet, skin on;
 - Fillet, skin off;
 - Whole;
 - WholeCRF (only for crayfish);
 - Muscle (only for crayfish).



Table 3-5: Tissue type categories for the biota tissue dataset.

No.	Original Tissue Type	Study ID	Species ¹	Notes on Changes to Tissue Type Designation in R Dataset
1	Fillet, skin on ²	AJOH0005	SMB, LMB, RBT, KOK, YP, WCP, MWF, NPM, BRT, WAL	
		AJOH0008	RBT, MWF	
		AJOH0022	LSS, RBT, MWF	
		DSER0010	RBT	
		DSER0016	BLS, SMB, RBT, MWF, BRT	
		RJAC002	LSS, SMB, LMB, YP, MWF	
		WSTMP03T	RBT	
		WSTMP12	LSS, RBT, MWF, NPM, BRT	
2	Fillet portion (epaxial muscle), skin off ³ Tissue type 2 relabeled as "Fillet, skin off"	DSER0002	LMB, YP	
		WSPMP93T	RBT	
3	Muscle ⁴	AJOH0005	CRF	Tissue type for DSER0010 CRF was relabeled "Muscle" (originally Type 5)
		DSER0010	CRF	
4	Whole organism (animal) ^{5a} Tissue type 4 relabeled as "Whole"	AJOH0005	CRF , LSS	CRF tissue type changed to "Muscle" ^{5b, Ref a, b, c}
		AJOH0008	LSS	
		AJOH0022	LSS, RBT, MWF, CRF	CRF tissue type relabelled to "WholeCRF"
		BERA0011	CCP	
		DSER0002	LSS	
		DSER0010	BLS, LSS	
		DSER0016	BLS, LSS, RBT, MWF	
		mifr0003	RBT	
		RJAC002	LSS	
		WSPMP93T	LSS	
		WSTMP12	LSS	
5	Whole organism, not exoskeleton or shell, not gut ^{6a} Tissue type not carried forward	DSER0010	CRF	CRF tissue type relabelled "Muscle" ^{6b, ref e}
6	Whole organism, not fillets ⁷ Tissue type not carried forward	DSER0016	BLS, RBT, MWF	Multiple tissue types; this type not carried forward ⁷
		WSTMP12	LSS	
7	Added tissue type 7 "WholeCRF"	AJOH0022	CRF	Tissue type for AJOH0022 CRF was relabeled "WholeCRF" (originally Type 4)



Table Notes:

~~Strikethrough~~ - denotes tissue type changed or relabelled.

¹ See species list in Note 5 for corresponding common and scientific names.

² Slime and scales removed and then rinsed with tap and then deionized water. Fish then filleted with skin left on and homogenized. ^{Ref g, h}

³ Muscle tissue samples prepared by compositing ~40 g of skinless epaxial muscle from each individual fish. ^{Ref f} Tissue type renamed "Fillet, skin off"

⁴ Abdominal (tail) muscle. ^{Ref a}

^{5a} Ageing structures removed and remaining whole organism homogenized. ^{Ref g, h} Tissue type renamed "Whole".

^{5b} Tissue type designation of CRF Sample ID: 94318265 in AJOH0005 appears erroneous in the EIM database; all other samples collected during the program designated as "muscle"; data reported by Ecology as "muscle" or "fillet" ^{Ref a, b and d} ; "Whole organism (animal)" changed to "Muscle".

^{6a} Corresponds to "tail muscle" i.e., the entire tail muscle (4-5 g) was removed from the exoskeleton and homogenized. ^{Ref e}

^{6b} CRF Sample ID: 4208148 in DSER0010 reported as "tail muscle" ^{Ref k} (i.e., tissue type is the same as "Muscle", but was named differently in the EIM database).

⁷ Corresponds to carcass (skin, bone, remaining soft tissues); fillets were removed and analyzed separately. Carcass samples were dropped as other tissue types were available for these fish:

DSER0016: BLS weighted whole body average data used "Whole" for Sample ID 05424257-05424258 (Dropped carcass and fillet samples: 5424257 and 5424258)

DSER0016: RBT fillet data used "Fillet, skin on" for Sample ID 5494272 (Dropped carcass and whole samples: 5524719 and 05494272-05524719)

DSER0016: MWF fillet data used "Fillet, skin on" for Sample ID 5494271 (Dropped carcass and whole samples: 5524718 and 05494272-05524719)

WSTMP12: LSS fillet data used "Fillet, skin on" for Sample ID 1301011-96 (Dropped carcass sample: 1301011-48; whole not available)

Table References

^a Ecology (Washington Department of Ecology). 1995. Department of Ecology 1993-94 Investigation of PCBs in the Spokane River. Washington State Department of Ecology. Olympia, WA.

^b Davis, D., Serdar, D. 1994. Results of 1993 screening survey on PCBs and Metals in the Spokane River (with corrections). Washington State Department of Ecology. Olympia, WA.

^c Johnson, A. 1994(a). Planar PCBs in Spokane River Fish. Toxics, Compliance, and Ground Water Investigations Section - Washington State Department of Ecology. WA.

^d Johnson, A. 1994(b). PCB and Lead Results for 1994 Spokane River Fish Samples. Toxics Investigation Section - Washington State Department of Ecology. WA.

^e Serdar, D., Lubliner, B., Johnson, A., Norton, D. 2011. Spokane River PCB Source Assessment 2003-2007. Washington State Department of Ecology. Olympia, WA.

^f Serdar, D., Johnson, A., Davis, D. 1994. Survey of Chemical Contaminants in Ten Washington Lakes.

^g Serdar, D., Johnson, A. 2006. PCBs, PBDEs, and Selected Metals in Spokane River Fish, 2005. Washington State Department of Ecology. Olympia, WA.

^h Serdar, D. 2013. Quality Assurance Project Plan: Freshwater Fish Contaminant Monitoring Plan. Washington State Department of Ecology. Olympia, WA.



3.4. Identifier Fields for Grouping Data

Identifier columns were added in the R analysis to enable grouping data by various categories. These fields include:

1. "AnalysisType" was added to classify constituents as:
 - a. Aroclor – PCB Aroclors,
 - b. Congener – individual PCB congeners,
 - c. Supporting – ancillary data (e.g., lipid content, TOC content, TSS, etc.),
 - d. Sum Aroclors – sum of individual Aroclors for tPCB calculation (see [Section 2.2.1](#) for detection limit treatments in the database),
 - e. Sum Congeners – sum of individual congeners for tPCB calculation (see [Section 2.2.1](#) for detection limit treatments in the database).
2. "LimitType" assigned PCB constituents as "Zero", "Half" or "Full" (corresponding to the tPCB treatments shown in [Section 2.2.1](#)).
3. Date specifier columns were also added to group data by "Year" or "Decade".
4. Scenario columns were added to categorize data as "Baseline" or "Current", for example, and select relevant studies representing years of interest (see [Table 3-1](#) and [Table 3-2](#)).
5. A "RiverStretch" column was added to assign samples based on River Mile according to compartments that have been designated for the project. The "RiverStretch" categories are generally split by dam locations in the Spokane River, the exception being that the Stateline is used rather than Post Falls Dam ([Table 3-6](#)).

Table 3-6: River stretch categories used for data analysis.

River Stretch	River Miles
AboveStateline	RM 112-96.1
AboveUpriver	RM 96.1-80.2
AboveMonroe	RM 80.2-74.0
AboveNinemile	RM 74.0-58.1
LakeSpokane	RM 58.1-33.9
AboveLittleFalls	RM 33.9-29.3
SpokaneArm	RM 29.3-0



6. "TaxonName" – this column was originally in the database and contained the Latin names of species collected in the Spokane River studies (although crayfish was sometimes identified by family name only). Additional identifier columns were added to group or display species by "CommonName", "SpeciesCode", and "TaxonGroup", which were used for tables and figures.

Table 3-7: Species names and classifiers used for the biota tissue dataset.

Common Name	Species Code ¹	Taxon Name	Taxon Group
Bridgelip Sucker	BLS	<i>Catostomus columbianus</i>	Sucker
Brown Trout	BRT	<i>Salmo trutta</i>	Other
Common Carp	CCP	<i>Cyprinus carpio</i>	Common Carp
Crayfish ²	CRF	Astacidae	Crayfish
Crayfish (Signal Crayfish)	CRF	<i>Pacifastacus leniusculus</i>	Crayfish
Kokanee	KOK	<i>Oncorhynchus nerka</i>	Other
Largemouth Bass	LMB	<i>Micropterus salmoides</i>	Other
Largescale Sucker	LSS	<i>Catostomus macrocheilus</i>	Sucker
Mountain Whitefish	MWF	<i>Prosopium williamsoni</i>	Mountain Whitefish
Northern Pikeminnow ³	NPM	<i>Ptychocheilus oregonensis</i>	Other
Rainbow Trout	RBT	<i>Oncorhynchus mykiss</i>	Rainbow Trout
Smallmouth Bass	SMB	<i>Micropterus dolomieu</i>	Other
Walleye	WAL	<i>Sander vitreus</i> ⁴	Other
White Crappie	WCP	<i>Pomoxis annularis</i>	Other
Yellow Perch	YP	<i>Perca flavescens</i>	Other

Table Notes:

¹ Species codes were selected from Spokane River studies and are used for this project.

² In some reports, Crayfish was only identified to the family level (Davis and Serdar 1994, Johnson 1994a).

³ Previously referred to as Northern Squawfish.

⁴ Previous scientific name was *Stizostedion vitreum*.



7. Depth categories of "surface" and "subsurface" were added for sediments. Surface included most of the samples and was assigned as the top 10 cm when sampling was in 10 cm intervals, or the top 2 cm of core samples (which had 1 or 2 cm depth intervals). Surface was also assigned in cases where depth was undefined after these studies were confirmed not to be coring programs.

3.5. QAQC

QAQC review of the dataset preparation/clean-up steps in R was conducted throughout the process by reviewing outputs with an emphasis on data to which changes were made (as described in this section) and spot-checking other results.



4. CALCULATIONS & ANALYSIS

4.1. Detection Limit Treatments

Data were explored to examine the influence of the detection limit assumptions on the resulting tPCB concentrations. For this analysis, three ratios were calculated for tPCB parameters:

1. RatioNDs: $\frac{\text{CountOfNDs}}{\text{CountOfAnalyses}}$

Where "CountOfNDs" is the number of non-detect congeners/Aroclors comprising tPCB results in a sample and "CountOfAnalyses" is the total number of congeners/Aroclors measured in a sample. This ratio was used to examine how PCB concentrations varied with the proportion of non-detect parameters comprising the tPCB measurement.

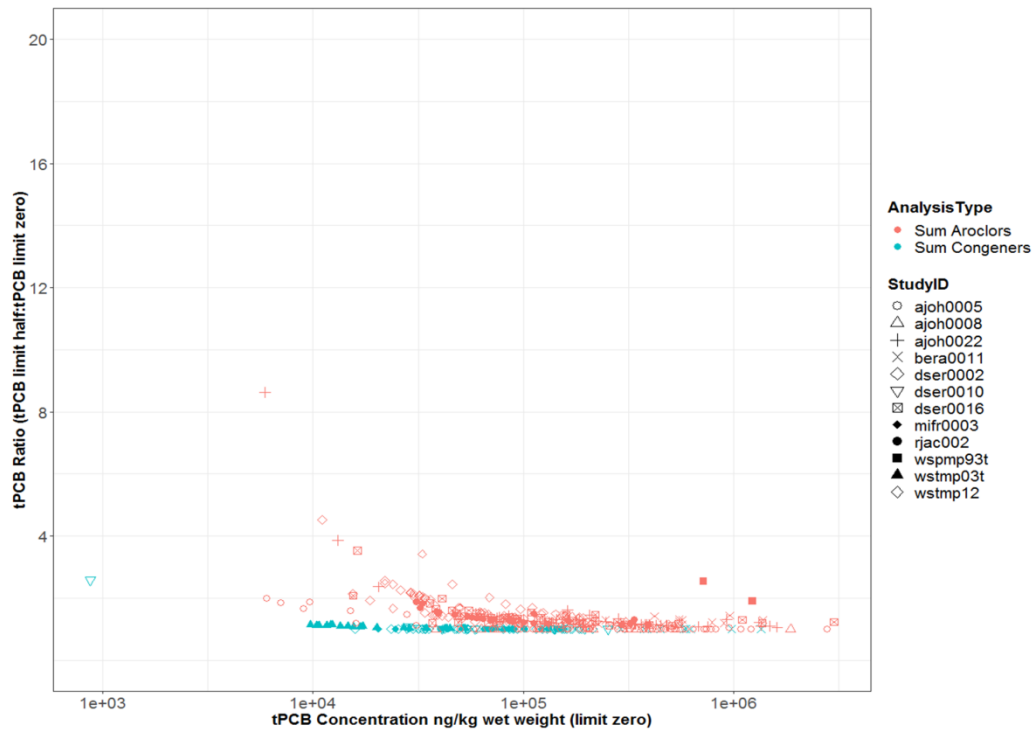
As well, ratios were calculated for tPCB concentrations for the same sample obtained using different detection limit treatments:

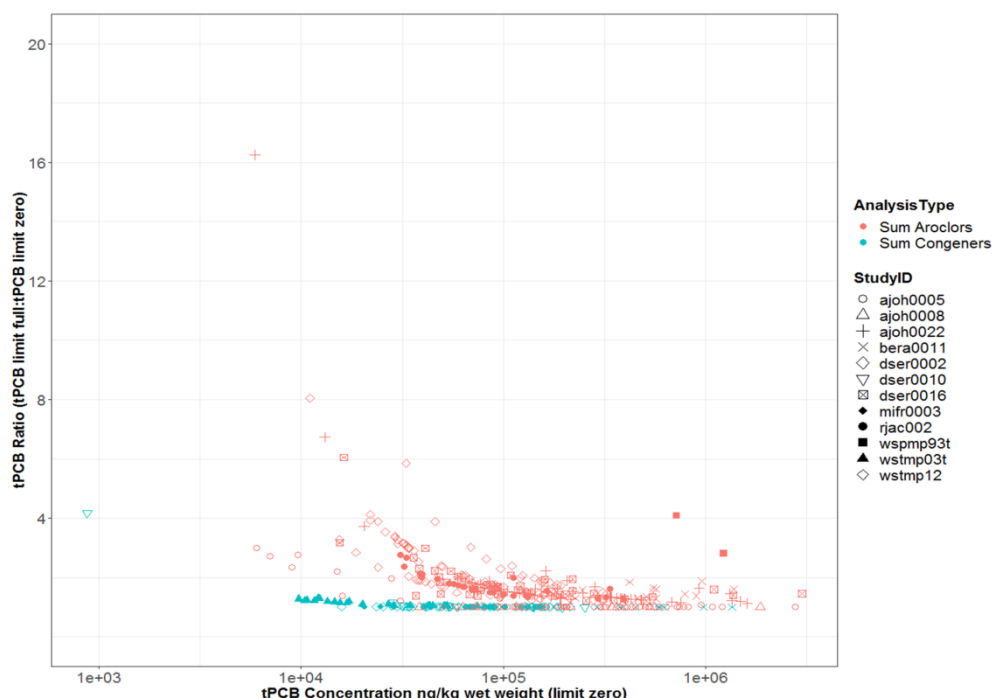
2. tPCB "full" ratio: $\frac{tPCB-Limit}{tPCB-LimitZero}$
3. tPCB "half" ratio: $\frac{tPCB-Limit/2}{tPCB-LimitZero}$

A ratio of one indicates that the tPCB half/full and tPCB zero concentrations are the same. A ratio above one indicates that tPCB half/full concentration is greater than tPCB zero concentration. These ratios are plotted as a function of the tPCB "zero" limit concentration (see [Figure 4-1](#) example for fish tissue data).



Figure 4-1: tPCB ratios for different detection limit treatments as a function of tPCB concentration (limit zero, ng/kg wet weight). Top plot shows "half" ratio, bottom plot shows "full" ratio. Aroclor data are shown in orange and congener data are shown in teal.





The plots show that when tPCB concentrations are low, and there are more non-detect PCB congeners or Aroclors in the sample, the non-detect data have a greater influence on the tPCB concentration and result in larger differences between the full/half treatments and the zero treatment, than at higher tPCB concentrations. tPCB measured by Aroclor shows a larger difference between the full/half treatment versus the zero treatment than tPCB determined by congener analysis, at low tPCB concentrations. Samples analyzed by congener methods show minor spread between tPCB values using all three detection limit treatments.

4.2. tPCB Data Analysis

At the request of the Expert, several analyses were conducted on the datasets.

4.2.1. General

Summary statistics were calculated to describe tPCB concentrations and ancillary data from multiple individual samples of different media. Different approaches were used and were provided for use in the Expert Report. PCB concentration data from individual samples were grouped by: year/scenario, river stretch, analysis type, detection limit treatment type, and species and tissue type for tissue data, for the calculation of descriptive statistics.

4.2.1.1. Summary Statistics for Calculating Arithmetic Averages

Basic descriptive statistics were calculated for each media and spatial/temporal grouping (as described above). Statistics included:



- Sample size;
- Arithmetic means (or averages);
- Minimum values;
- Maximum values.

Parameters summarized include:

- tPCB concentrations in original units for each media: wet weight (ng/kg ww) in biota, dry weight (ng/kg dw) in sediment, and by volume (ng/L) in water.
- tPCB concentrations were also normalized to ancillary data by dividing the tPCB concentration by the lipid or TOC content (see equations below).
- Ancillary data were summarized such as lipid contents in tissue and TOC contents in sediments.
- Count of PCB analytes, count of non-detects, and ratio of non-detects (as described in [Section 4.1](#)).

4.2.1.2. Log Transformation & Statistics for Calculating Geometric Means

In addition to calculation arithmetic averages, tPCB concentration data were logarithm base 10 (log-10) transformed for statistical analysis. This approach can be used for summarizing concentration data in environmental media, as concentration data are often log-normally distributed. Summary statistics were then calculated on a log-10 basis, yielding geometric means and standard deviations that are factors of the mean, when converted back to original units. One aspect of the log-10 transformation is that tPCB results that are zero (i.e., tPCB less than detection limit for the zero treatment) are removed because the log-10 of zero is undefined. This was the case for a relatively small proportion of the tissue, sediment and water dataset, with most non-detect samples from earlier studies. Non-detect tPCB values using the two other data treatments were non-zero due to half or full detection limit substitutions and were retained in the analysis.

Log-10 transformed statistics included:

- Log-10 unit mean;
- Geometric mean, when log-10 means are converted to original units (i.e., antilog of mean log-10 tPCB);
- Log-10 unit standard deviation;
- Standard deviation equaling a factor of the geometric mean, when log-10 standard deviations are converted to original units (i.e., antilog of mean log-10 tPCB);
- Upper and lower 1 x standard deviation limits of the geometric mean. These were calculated as geometric mean multiplied (upper) or divided (lower) by the standard deviation factor;



- For some analyses, upper and lower 95% confidence intervals of the geometric mean were calculated $1.96 \times$ standard deviation. These were calculated in log space and then converted to original units by taking the antilog.

Parameters summarized using this approach include:

- tPCB concentrations in original units for each media: wet weight (ng/kg ww) in biota, dry weight (ng/kg dw) in sediment, and by volume (ng/L) in water.
- tPCB concentrations normalized to ancillary data (see below).

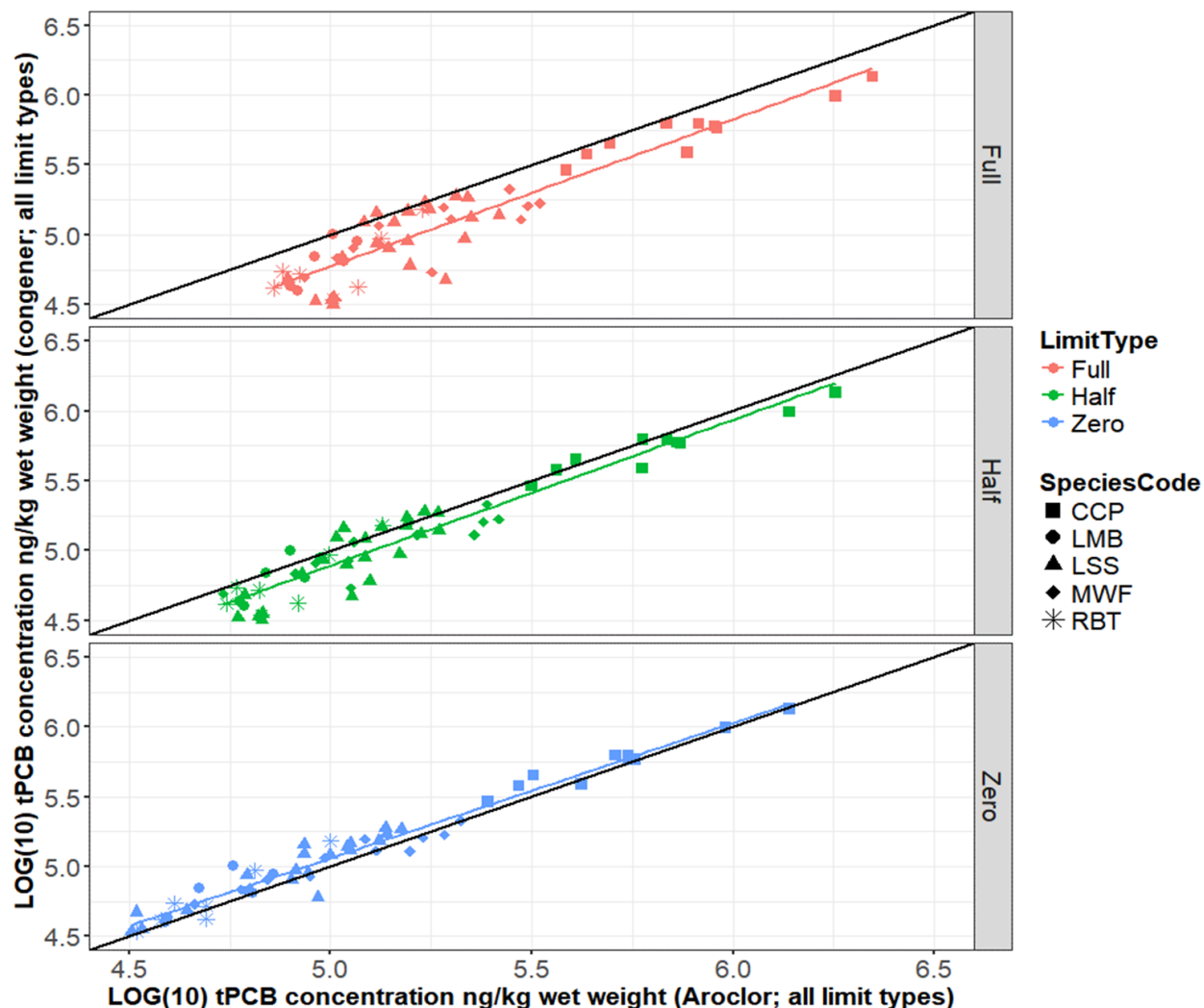
4.2.2. Tissue-specific

4.2.2.1. Regression between tPCB Analyzed by Aroclor and tPCB Analyzed by Congener Methods

To examine potential differences between tPCB results obtained by Aroclor and congener methods, a regression analysis was completed on fish tissue samples analyzed by both methods. Specifically, three studies (i.e., BERA0011, RJAC002, and WSTMP12) analyzed a total of 60 fish samples using both congener and Aroclor methods. Quantitative regression relationships between tPCB Aroclor and tPCB congener are shown in **Figure 4-2**.



Figure 4-2: tPCB concentration by congener versus tPCB by Aroclor (logarithm base 10 transformed values, ng/kg wet weight, for all detection limit treatments).



The black lines in **Figure 4-2** represent a 1:1 relationship between tPCB Aroclor and tPCB congener. The colored lines are best-fit for each of the detection limit treatments for non-detect data. While tPCB concentrations in common carp (study BERA0011) were higher than those in other fish species, there was no apparent bias related to species (i.e., data points for different species fall above and below the regressions lines equally; **Figure 4-2**). All best-fit regression lines are similar to the 1:1 line, with tPCB Aroclor being slightly lower than tPCB congener for the zero detection limit treatment, and, conversely, tPCB Aroclor is somewhat higher than tPCB congener for the half and full detection limit treatments.

The statistics shown in **Table 4-1** indicate very strong statistically significant relationships for all limit types (i.e., p values for the slope much less than 0.01). Much of the variability in the data is explained by the linear regression models for the log-10 versus log-10 transformed values (i.e., high R-squared values for each limit type). The residual standard error represents the differences between the predicted values and the values used to fit the model and reflects any sources of variability that are not captured by the regression, such as natural variation among individual fish and laboratory measurement error.

Table 4-1: tPCB congener versus tPCB Aroclor (LOG(10) tPCB; ng/kg wet weight) regression coefficients and statistics

LimitType	<i>m</i> (slope)	Standard error (<i>m</i>)	p value (<i>m</i>)	<i>b</i> (y-intercept)	R-squared	Residual Standard Error
Zero	0.984	0.032	<0.01	0.130	0.94	0.101
Half	1.088	0.048	<0.01	-0.569	0.90	0.134
Full	1.100	0.063	<0.01	-0.756	0.84	0.166

4.2.2.2. Lipid Normalization

For fish and other biota samples, lipid normalized tPCB concentrations (C_{fish-L} , ng/kg lipid) were calculated from the wet weight concentration in fish (C_{fish} , ng/kg wet weight) and percent lipid content (L , %), according to **Equation 2**:

Equation 2: Lipid normalization.

$$C_{fish-L} = \frac{C_{fish}}{L/100\%}$$

An example lipid normalized calculation is show in **Table 4-2**.

Table 4-2: Example calculation for lipid normalization.

Study ID: DSER0010		
Sample ID: 4324444		
Parameter	Value	Units
C _{fish} =	195,360	ng/kg wet weight
L =	7.7	%
C _{fish-L} =	2,537,143	ng/kg lipid



4.2.2.3. Temporal Trends Analysis

Methods

A temporal trends analysis was conducted on the fish tissue PCB concentration data in two ways:

- 2012 versus 2005 – data from the most comprehensive studies representing the baseline period (DSER0016, 2005) and the recent intermediary period of 2012 (WSTMP12, 2012) were tested to see if there were statistically significant differences in tPCB concentrations in fish between these years.
- Temporal trends over time (1990s to 2012) – the overall fish tissue dataset was tested to determine whether there are statistically significant temporal trends in tPCB concentrations in Spokane River fish over time.

Data treatment for this analysis included:

- Limiting the dataset to three species for which data support temporal analyses: Largescale Sucker-whole body (LSS), Rainbow Trout-fillet skin on (RBT), and Mountain Whitefish-fillet skin on (MWF). (Species acronyms are used in tables and figures).
- Using five Spokane River stretches with sufficient PCB data for the analysis. From upstream to downstream these reaches include: Above Stateline, Above Upriver, Above Monroe, Above Nine Mile, and Lake Spokane.
- Log-10 transforming the data due to the log-normal nature of the concentration data. Rare cases of zero tPCB values were removed from the log-10 dataset.
- tPCB results obtained using both Aroclor and congener analytical methods were used in this trend analysis.
- The data were tested using three different treatments of non-detect values (see [Section 2.2.1](#)) and using both wet weight and lipid normalized concentrations, for a total of six data sets: LimZero, LimZero-Lipid, LimHalf, LimHalf-Lipid, LimFull and LimFull-Lipid.
- For the 2012 versus 2005 analysis, the differences between mean tPCB values for the two years were tested using a simple linear model (analysis of variance, ANOVA). Statistical p-values and direction of change from 2005 to 2012 are reported. Given limited data, significance of $p \leq 0.1$ was highlighted for cases where concentrations declined over time. ANOVA tests were only conducted for reaches/species where there were at least two samples for each of 2005 and 2012. Overall, there were 10 cases tested: four reaches for Largescale Sucker and three reaches each for Mountain Whitefish and Rainbow Trout.
- For temporal trends over time (1990s to 2012), a linear mixed-effect model was applied to the log-10 data. Statistical p-values, and fixed-effect intercepts and slopes were reported. Results with a significance level of $p \leq 0.05$ and negative slope were highlighted. Statistical tests were



only conducted for reaches/species where there were at least three years of data available. Overall, there were 11 cases tested: five reaches for Largescale Sucker and three reaches each for Mountain Whitefish and Rainbow Trout.

The linear regression model, where Year (t) is the key source of replication with subsampling (s) within year, followed **Equation 3**:

Equation 3: Linear mixed-effect regression model of PCBs over time.

$$LOG_{10}tPCB = B0 + B1 \times Year_t + b0_t \times Year.fac_t + error_ts$$

Where

B0 = intercept (fixed effect),

B1 = slope (fixed),

Year_t = year as continuous variable,

b0_t = random effects (intercept) representing year-specific differences in mean about the trend,

Year.fac_t = year treated as a factor (grouping variable for subsamples [s], and error_ts = residual error.

- The regression analysis was run in R statistical software using the lme4 package as follows:

```
lmer (log.PCB ~ Year + (1 | Year.fac), data=data)
```

- The R package lmerTest was used to evaluate the significance (p-value) of B1 (the overall slope), which is the key output of interest.
- This model assumes there is no autocorrelation (additional time structure) across years (i.e., b0_t are assumed to be independent and identically distributed normal variables), which is reasonable in this case, and could not be discerned anyway given the small number of years.
- Note: the lmer form "(1|Year.fac)" is simply recognizing that there are multiple samples collected each year and that we can expect the samples for a given year to have a different 'mean' (i.e., intercept) than the samples collected in other years. This allows the model to expect that there will be multiple data points per year. Failure to account for this structure would result in a simple linear regression model that does not meet the assumption of independence of data points.



Results

Results for 2012 versus 2005 analysis are shown in **Table 4-3**.

Table 4-3: 2012 versus 2005 ANOVA of tPCB concentrations in fish from the Spokane River.

Top table is LimZero and LimZero-Lipid; middle is LimHalf and LimHalf-Zero and bottom is LimFull and LimFull-Zero

River Stretch	2012 versus 2005: Linear Models (ANOVA) Results					
	Data Set: LimZero			Data Set: LimZero-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.82 -			0.14 +		
AboveUpriver	0.95 -		0.04 -	0.82 -		0.29 -
AboveMonroe	0 -	0.03 -	0.27 -	0 -	0.09 -	0.28 -
AboveNinemile		0.61 -	0.11 -		0.05 -	0.04 -
LakeSpokane	0.21 -	0.15 +		0.12 +	0.12 +	

River Stretch	2012 versus 2005: Linear Models (ANOVA) Results					
	Data Set: LimHalf			Data Set: LimHalf-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.89 -			0.13 +		
AboveUpriver	0.91 -		0.01 -	0.8 -		0.08 -
AboveMonroe	0 -	0.02 -	0.11 -	0 -	0.07 -	0.16 -
AboveNinemile		0.52 -	0.01 -		0.03 -	0 -
LakeSpokane	0.06 -	0.26 +		0.17 +	0.21 +	

River Stretch	2012 versus 2005: Linear Models (ANOVA) Results					
	Data Set: LimFull			Data Set: LimFull-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.88 -			0.2 +		
AboveUpriver	0.84 -		0 -	0.76 -		0.03 -
AboveMonroe	0 -	0.02 -	0.06 -	0 -	0.06 -	0.11 -
AboveNinemile		0.48 -	0 -		0.04 -	0 -
LakeSpokane	0.02 -	0.71 +		0.26 +	0.63 +	

p value ≤ 0.10 and declining concentration from 2005 to 2012

p value > 0.10 with increasing or decreasing concentration from 2005 to 2012



Results show statistically significant declines in log-10 tPCB concentrations between 2005 and 2012, for five of ten species/river stretch cases tested, based on at least one of the LimZero/LimZero-lipid datasets. The other datasets (LimHalf, LimHalf-lipid and LimFull, LimFull-lipid) support these results and also suggest declines in tPCB concentrations in fish between 2005 and 2012 in an additional two species/river stretch combinations. By river stretch, results were:

- Above Stateline: No evidence of a decline over time for Largescale Sucker. (Largescale Sucker is the only species with data for this reach).
- Above Upriver: No evidence of a decline for Largescale Sucker, but evidence of a decline for Rainbow Trout. (No samples of Mountain Whitefish from this reach).
- Above Monroe: Strong evidence of a decline for Largescale Sucker and Mountain Whitefish. For Rainbow Trout, there is some uncertainty but no strong evidence of a decline. Specifically, results for the LimFull (wet weight) showed a decline, but none of the other data treatments were significant.
- Above Nine Mile: Strong evidence of a decline for Rainbow Trout. For Mountain Whitefish, there was strong evidence of a decline based on lipid normalized concentrations only. (There were insufficient data for Largescale Sucker from this reach).
- Lake Spokane: No evidence of changes for Mountain Whitefish. For Largescale Sucker, there is may be a weak indication of declining concentrations between 2005 and 2012, but there is uncertainty and differences between results obtained from different data treatment approaches. (i.e., the LimHalf and LimFull (wet weight) show declines, but these are not evident in the LimZero or any lipid normalized datasets). (No Rainbow Trout data from Lake Spokane).

Overall, these data indicate decreasing tPCB concentrations in fish from 2005 to 2012 for the mid Spokane River reaches of Above Upriver (one of two species), Above Monroe (two of three species), and Above Nine Mile (both species). No declines were observed Above Stateline and there was no clear evidence of declining concentrations in Lake Spokane.

Results for trend analysis over time (1990s to 2012) are shown in **Table 4-4** and in **Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6, Figure 4-7** and **Figure 4-8** for all data treatments.

Key results by river stretch were:

- Above Stateline: Some uncertainty, but no strong evidence of declining PCB concentrations over time for Largescale Sucker. Declines were only observed in the LimHalf and LimFull data treatments and not the LimZero or any lipid normalized dataset. (Largescale Sucker is the only species with data for this reach).
- Above Upriver: Strong evidence of declines for both Largescale Sucker and Rainbow Trout. (No samples of Mountain Whitefish from this reach).



- Above Monroe: Strong evidence of a decline for Mountain Whitefish only, not for Largescale Sucker or Rainbow Trout. Apparently, the decline in this stretch for Largescale Sucker from 2005 to 2012 is not consistent with the pattern observed over the entire time range; i.e., the 2005 data appear anomalously high relative to other years.
- Above Nine Mile: Some evidence of a decline for Largescale Sucker and Rainbow Trout. These were significant on a lipid normalized basis for the zero treatment (LimZero-lipid) and were supported by results of other data treatments, which were significant in some cases for Largescale Sucker or were marginal for Rainbow Trout, suggesting weaker declines. No evidence of a decline for Mountain Whitefish.
- Lake Spokane: No strong evidence of changes for Largescale Sucker and Mountain Whitefish. (No Rainbow Trout data from Lake Spokane).

Like the 2005 versus 2012 analysis, the regression analysis indicated decreasing tPCB concentrations of fish over time (1990s to 2012) for the mid Spokane River reaches of Above Upriver (both species), Above Monroe (one of three species), and Above Nine Mile (both species). Neither analysis detected statistically significant changes in tPCB concentrations in fish from the farthest upstream reach, Above Stateline, or in Lake Spokane.



Table 4-4: Linear regression analysis for temporal trends over time in tPCB concentrations in fish from the Spokane River.

Top table is LimZero and LimZero-Lipid; middle is LimHalf and LimHalf-Lipid and bottom is LimFull and LimFull-Lipid

River Stretch	Linear Mixed-Effect Models Over Time									Linear Mixed-Effect Models Over Time								
	p value trend direction			Data Set: LimZero			y- intercept			slope			p value trend direction			Data Set: LimZero-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.23 -			38.4			-0.017			0.26 -			63.3			-0.029		
AboveUpriver	0.04 -		0 -	117.2		170.3	-0.056		-0.083	0.01 -		0 -	141.1		180.2	-0.067		-0.087
AboveMonroe	0.87 +	0 -	0.71 -	-8.7	77.7	16.8	0.007	-0.036	-0.006	0.4 -	0.02 -	0.25 -	62.4	92.5	38.4	-0.028	-0.043	-0.016
AboveNinemile	0.1 -	0.37 -	0.06 -	142.0	37.9	110.2	-0.068	-0.016	-0.053	0 -	0.43 -	0.03 -	149.4	45.6	96.7	-0.071	-0.019	-0.045
LakeSpokane	0.12 -	0.33 -		49.1	63.1		-0.022	-0.029		0.18 -	0.36 -		65.9	51.7		-0.029	-0.023	

River Stretch	Linear Mixed-Effect Models Over Time									Linear Mixed-Effect Models Over Time								
	p value trend direction			Data Set: LimHalf			y- intercept			slope			p value trend direction			Data Set: LimHalf-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.05 -			40.4			-0.018			0.37 -			57.4			-0.026		
AboveUpriver	0.05 -		0.01 -	117.4		173.2	-0.056		-0.084	0.01 -		0 -	142.0		183.0	-0.068		-0.088
AboveMonroe	0.79 +	0.04 -	0.83 -	-17.8	75.0	13.5	0.012	-0.035	-0.004	0.5 -	0.01 -	0.42 -	53.1	87.8	34.3	-0.023	-0.041	-0.014
AboveNinemile	0.21 -	0.59 -	0.07 -	121.4	24.7	105.7	-0.058	-0.010	-0.050	0 -	0.6 -	0.06 -	133.5	32.4	92.0	-0.063	-0.013	-0.043
LakeSpokane	0.17 -	0.39 -		44.0	53.7		-0.019	-0.024		0.22 -	0.45 -		60.6	41.4		-0.027	-0.017	

River Stretch	Linear Mixed-Effect Models Over Time									Linear Mixed-Effect Models Over Time								
	p value trend direction			Data Set: LimFull			y- intercept			slope			p value trend direction			Data Set: LimFull-Lipid		
	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT	LSS	MWF	RBT
AboveStateline	0.05 -			40.2			-0.018			0.41 -			55.0			-0.024		
AboveUpriver	0.06 -		0.01 -	115.6		173.8	-0.055		-0.084	0.02 -		0 -	140.6		183.5	-0.067		-0.088
AboveMonroe	0.74 +	0.04 -	0.89 -	-24.5	69.2	11.2	0.015	-0.032	-0.003	0.58 -	0.02 -	0.54 -	46.4	85.5	31.8	-0.020	-0.039	-0.012
AboveNinemile	0 -	0.8 -	0.08 -	110.3	14.8	102.3	-0.052	-0.005	-0.049	0 -	0.75 -	0.09 -	126.0	22.3	88.6	-0.059	-0.008	-0.041
LakeSpokane	0.23 -	0.48 -		39.5	44.9		-0.017	-0.020		0.27 -	0.56 -		55.6	32.6		-0.024	-0.013	

p value ≤ 0.05 and declining concentration over time (1990s to 2012)
p value > 0.05 with increasing or decreasing concentration 1990s to 2012



Figure 4-3: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimZero (log-10 tPCB, ng/kg ww).

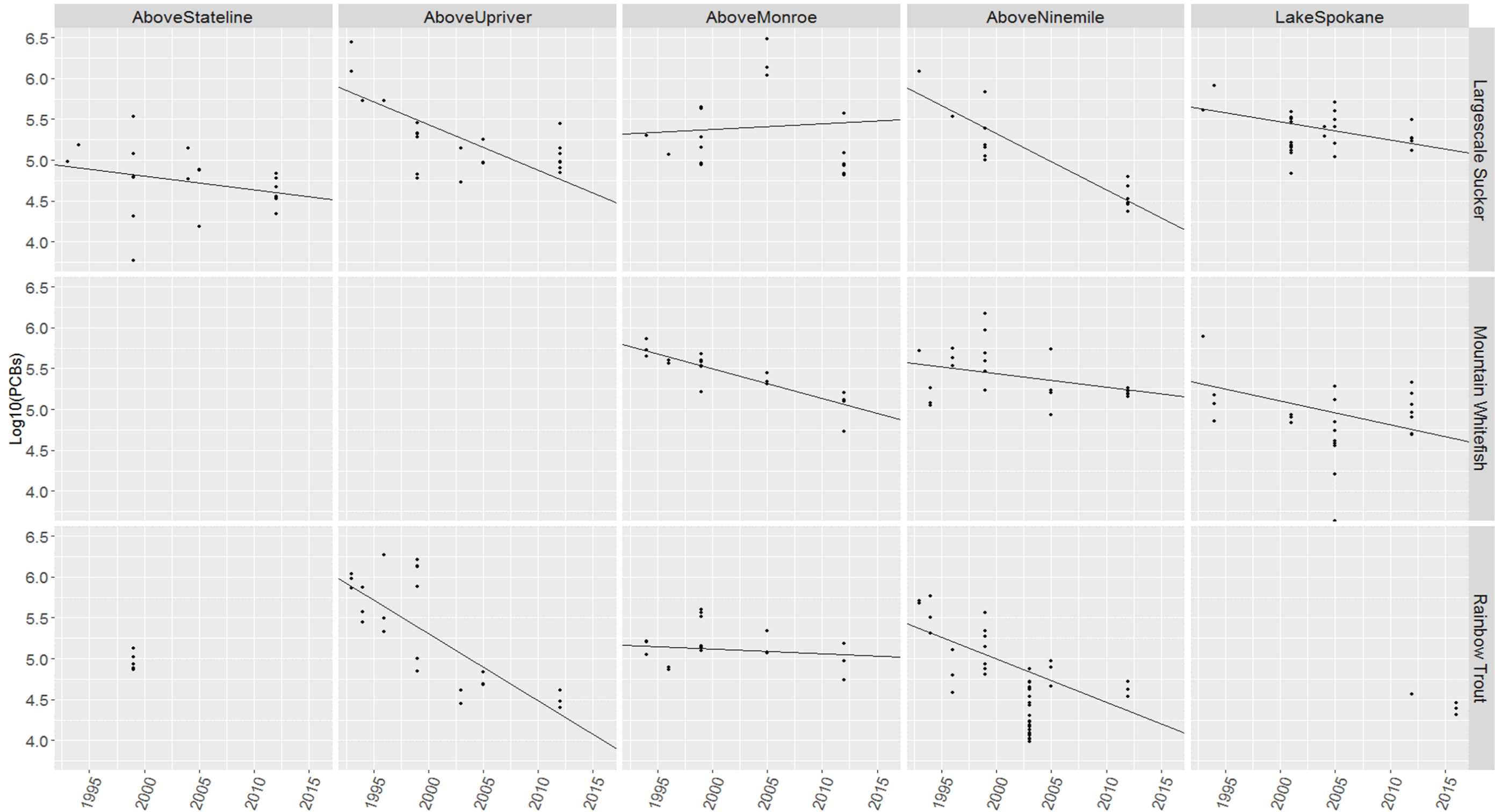


Figure 4-4: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimZero-Lipid (log-10 tPCB, ng/kg lipid).

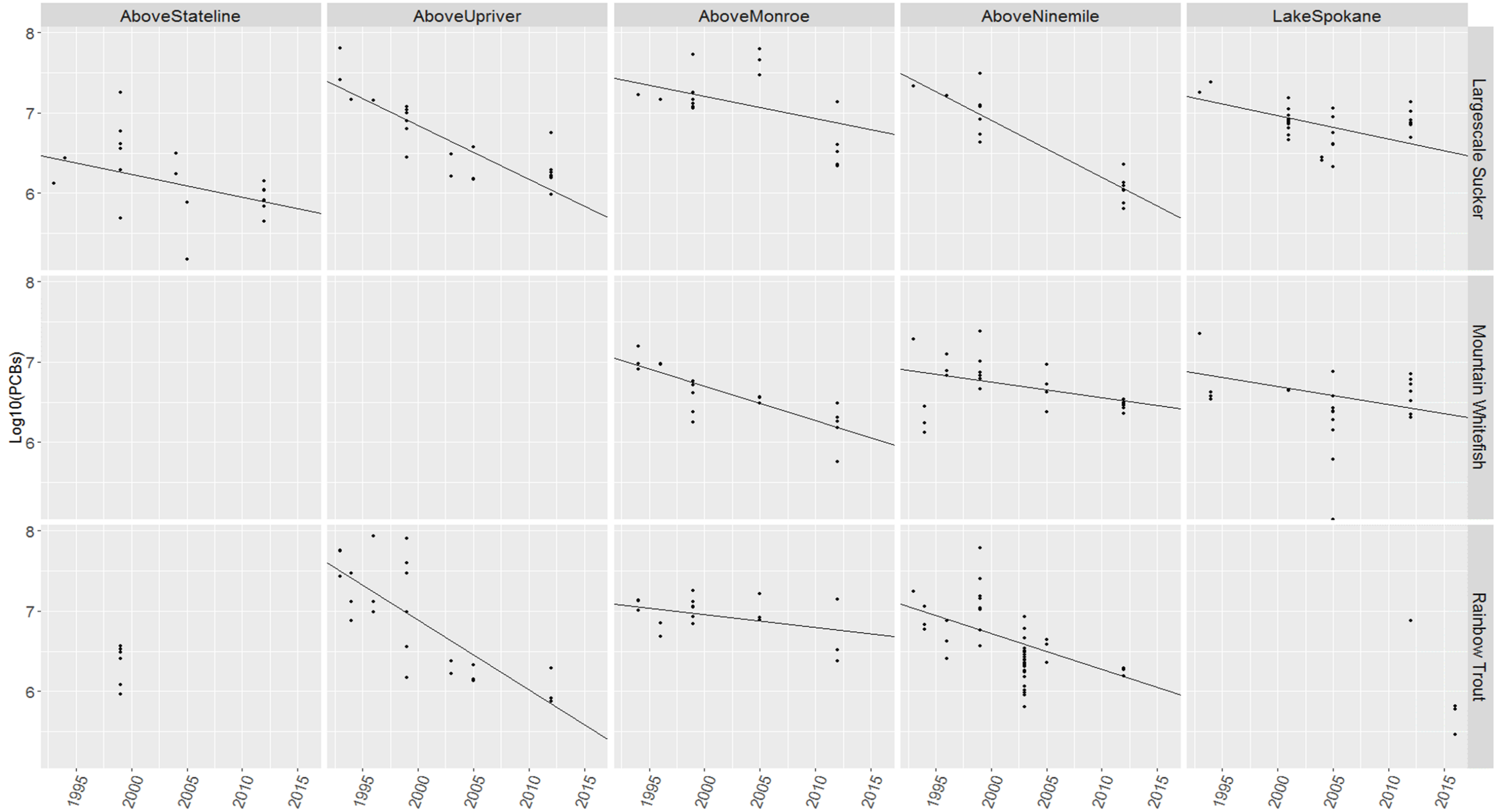


Figure 4-5: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimHalf (log-10 tPCB, ng/kg ww).

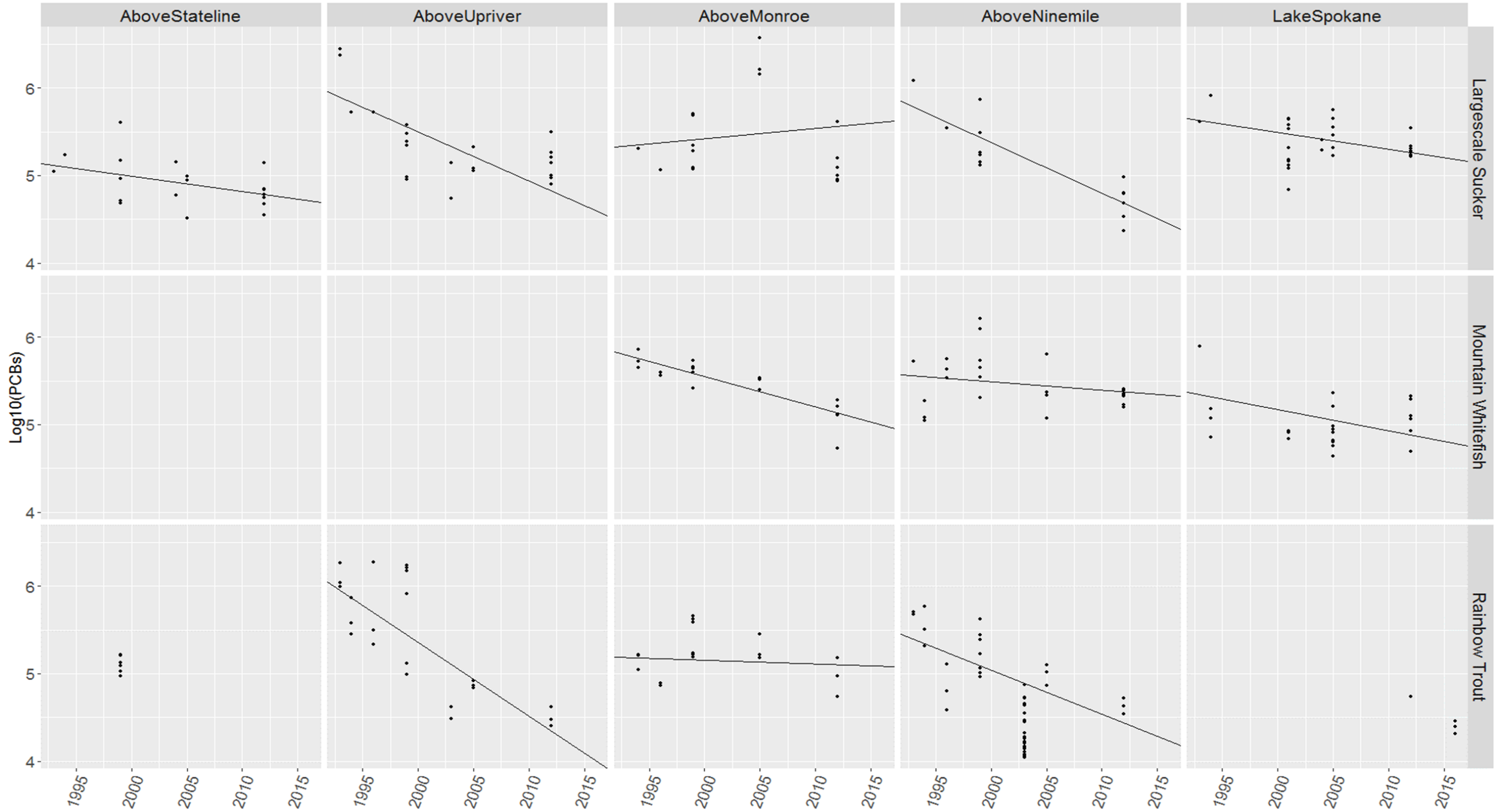


Figure 4-6: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimHalf-Lipid (log-10 tPCB, ng/kg lipid).

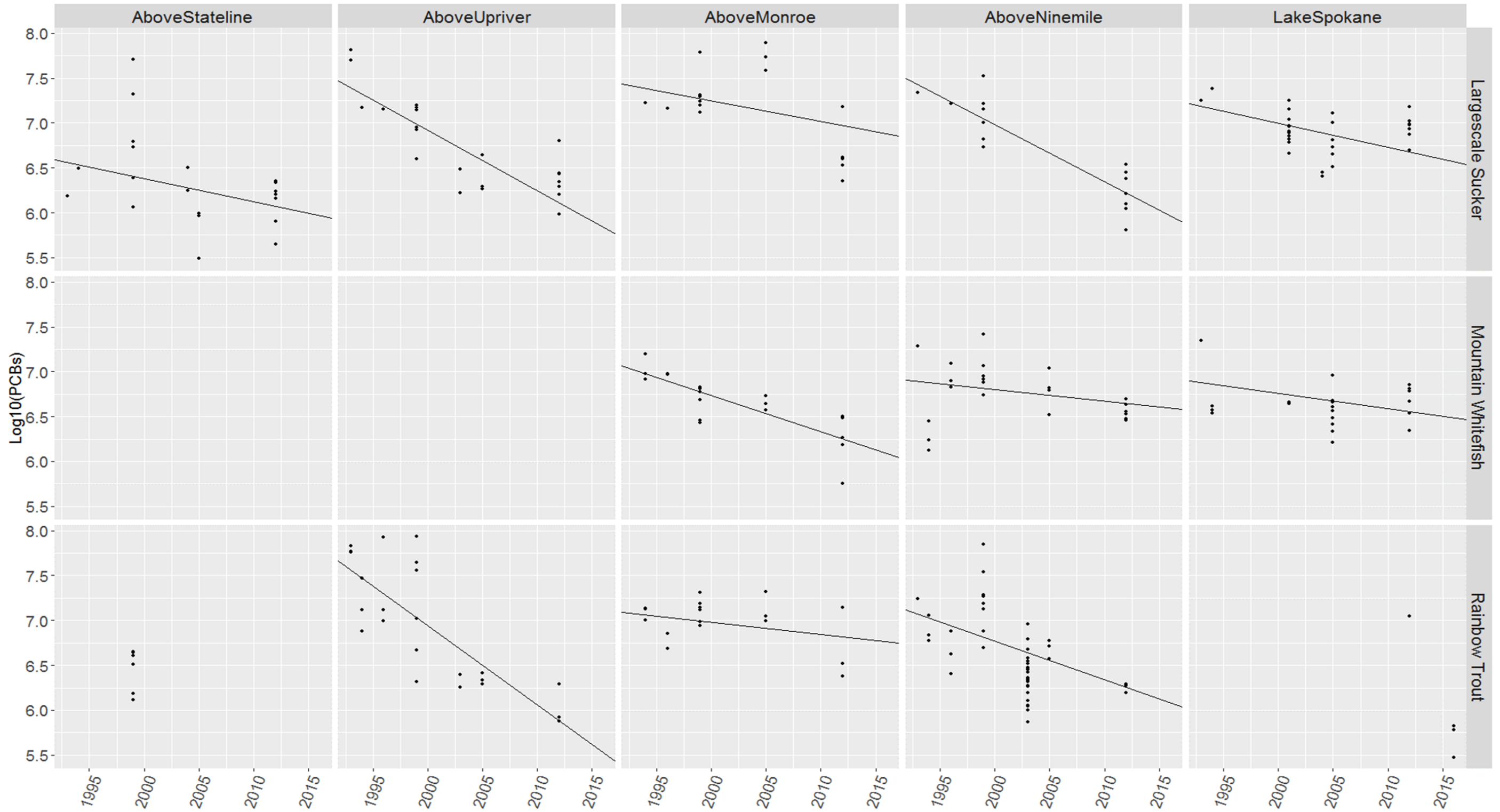


Figure 4-7: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimFull (log-10 tPCB, ng/kg ww).

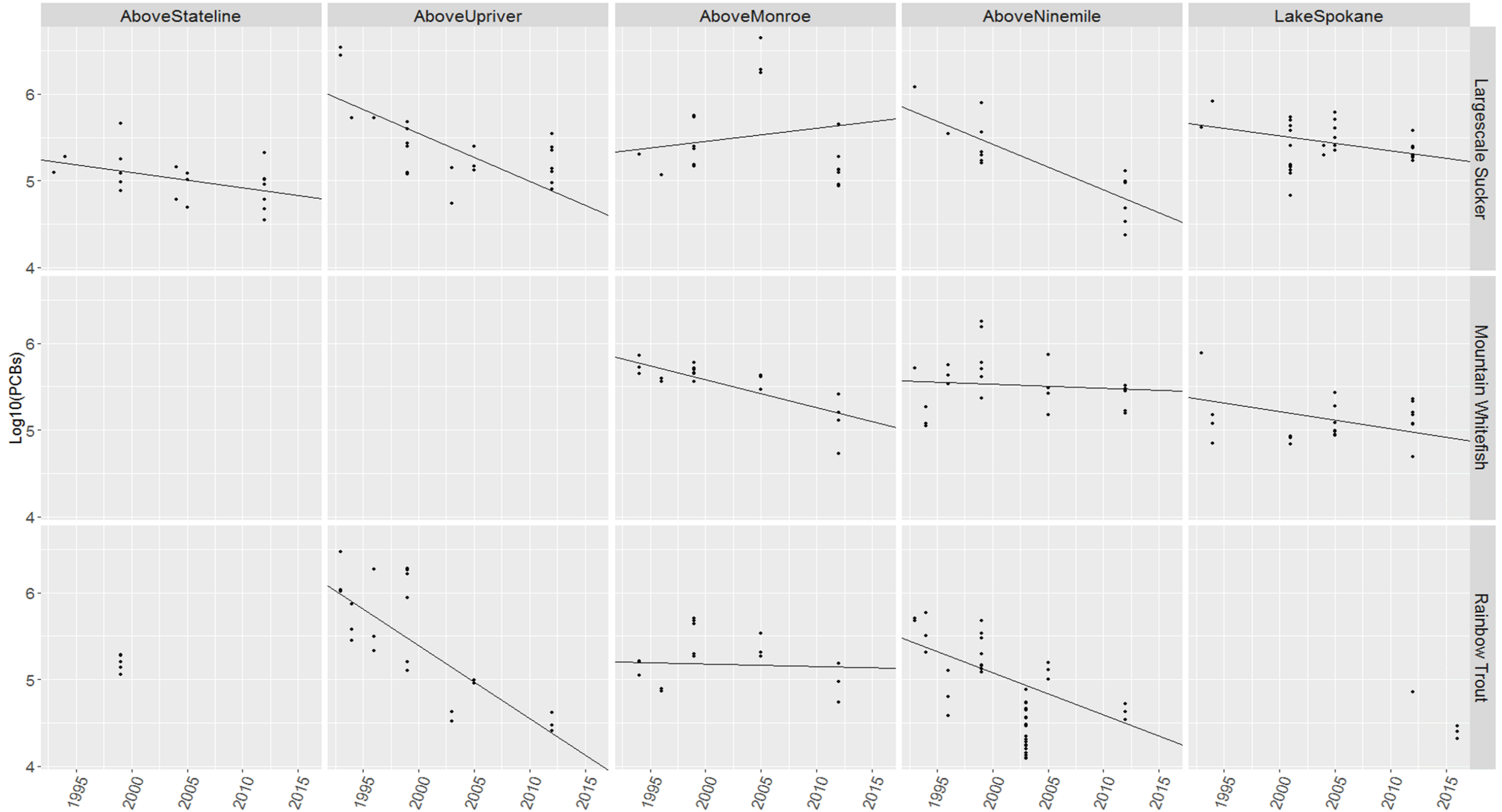
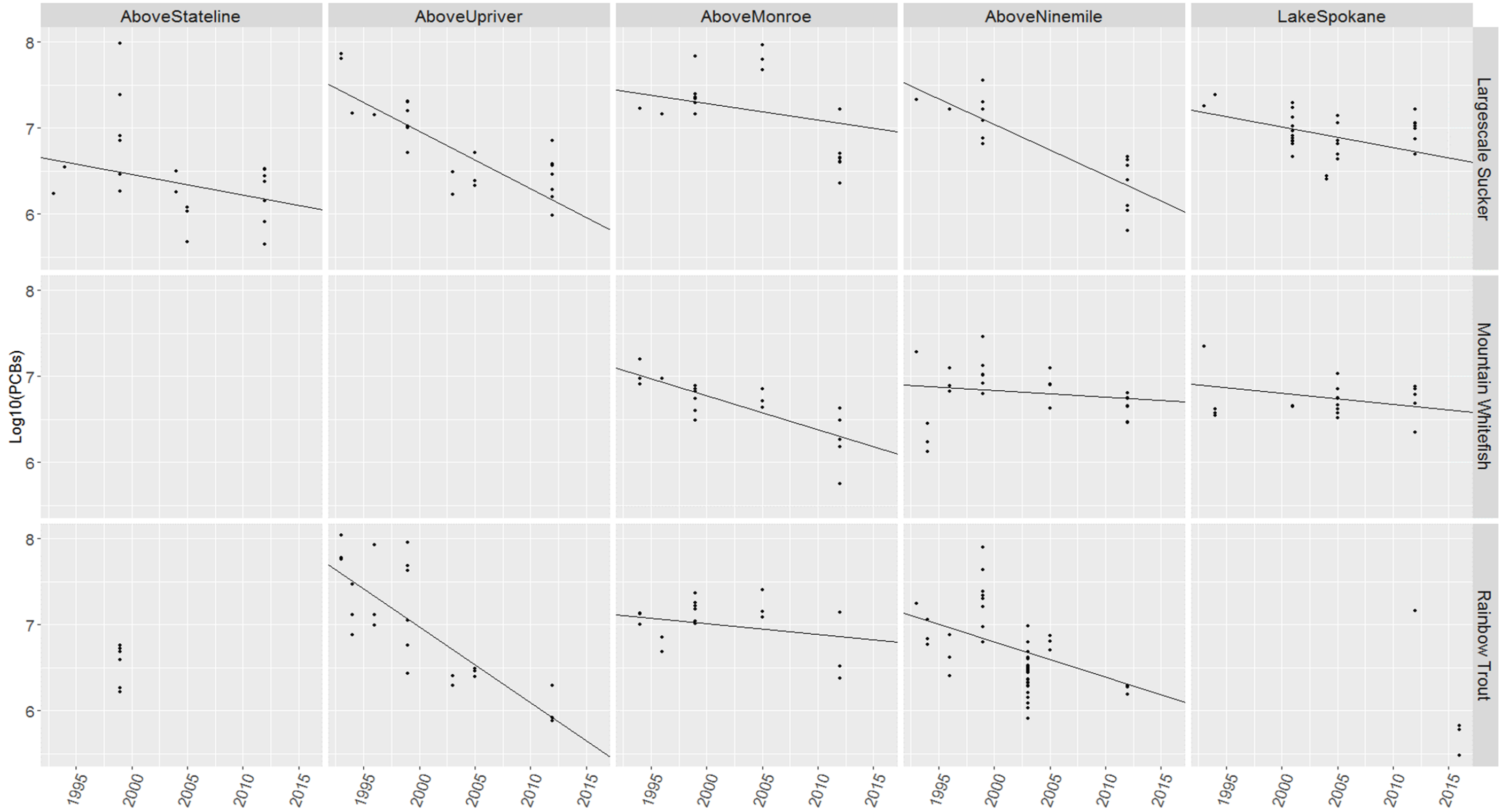


Figure 4-8: Regression models of tPCB concentrations over time by river stretch and species in fish from the Spokane River: Data set LimFull-Lipid (log-10 tPCB, ng/kg lipid).



4.2.3. Sediment and Suspended Sediment-specific

4.2.3.1. Total Organic Carbon Normalization

tPCB concentrations in sediment or suspended sediment (C_{sed} , ng/kg dry weight) were organic carbon-normalized ($C_{sed-toc}$, ng/kg TOC) using TOC (%) according to **Equation 4**:

Equation 4: Total organic carbon normalization.

$$C_{sed-toc} = \frac{C_{sed}}{TOC/100\%}$$

An example calculation is show in **Table 4-5**.

Table 4-5: Example calculation for organic carbon normalization.

Study ID: SRUW-Spokane		
Station ID: Avi-6		
Sample ID: 1308073-12		
Parameter: tPCB Congeners - LimitZero		
Parameter	Value	Units
Csed =	10,429	ng/kg dry weight
TOC =	1.13	%
Csed-toc =	922,920	ng/kg TOC

4.2.4. Water-specific

There were no calculations or data treatments, specific to the surface water data.

4.3. Compilation of Measured Concentrations of PCBs in Media of the Spokane River

Tables and figures summarizing the measured concentrations of tPCBs in fish, sediment, water, suspended sediment, biofilm and invertebrate samples from the Spokane River are provided in **Appendix A** of this memorandum. (Tables are provided electronically). In addition, **Appendix A** shows maps showing the locations where samples of different media were collected from the Spokane River.

4.4. Predictions of PCB Concentrations in Water, Sediments and Fish

Predicted concentrations of PCBs in water, sediment and fish of the Spokane River were calculated for the Expert Report by combining information on PCB discharge rates to the Spokane River (as described in the Expert Report), with the measured concentrations of PCBs in different media of the River (as compiled in this memorandum). The calculation of predicted concentrations of PCBs is possible due to the



linearity between changes in loadings and changes PCB concentrations. In other words, if combined PCB discharge rates to the Spokane River are reduced by 50%, for example, then concentrations of PCBs in water, sediment and fish are expected to decline in a proportional manner (i.e. by 50%) over time.

In order to predict PCB concentrations in media of the Spokane River, the first step was to calculate the relative change in combined PCB discharge rates between two time periods (e.g., current versus future 2030 or baseline versus current, etc.). For changes between baseline and current, there were two scenarios calculated based on the lower bound and upper bound loading estimates. For PCB loadings changes between baseline and future, there were a total of six scenarios calculated using three treatment levels for the City of Spokane's discharges, as well as lower and upper bound estimates for other sources. The scenarios are described in more detail in the Expert Report.

As an example, the relative change in loadings between future and current time periods is shown in **Equation 5** below:

Equation 5: Relative change in loadings between time periods.

$$\text{Relative Change in Loadings (fraction)} = \frac{\text{Sum PCB loadings}_{\text{Future}} - \text{Sum PCB loadings}_{\text{Current}}}{\text{Sum PCB loadings}_{\text{Current}}}$$

These changes in PCB loadings were calculated for various stretches of the Spokane River (**Table 3-6**). The PCB discharge rates for all known sources entering the Spokane River are provided in Expert Report.

These changes in PCB loadings in the Spokane River directly equate to expected changes in concentrations of PCBs in water, sediment and fish. Thus, the changes calculated using **Equation 5** were applied to the measured concentration of PCBs in media of the Spokane River, at a particular time point, to predict concentrations in the future or for other time periods. The predicted concentrations were calculated according to **Equation 6** for the future time period, as an example:

Equation 6: Calculation of predicted concentration of PCBs in media of the Spokane River.

$$\text{Future PCB Concentration} = (1 + \text{Relative Change in Loadings}) \times \text{Current PCB Concentration}$$

Where the Relative Change in Loadings is a fraction

This calculation can be made to represent changes from current to future, as shown, or for other time periods/scenarios, which are described in the Expert Report. Tables documenting the predicted



concentrations of PCBs in water, sediment and fish of the Spokane River are provided as electronic files in **Appendix A** of this memorandum.

4.5. QAQC Review

A QAQC review of all calculations and analyses was conducted by reviewing equations used in the R code and spot-checking the calculated values (i.e., for several samples, newly-calculated parameter values in the R output file were cross-checked with values calculated separately in Excel). The same approach was used for reviewing calculations of arithmetic, log-10 and geometric mean values and other statistics for all parameters (i.e., for various groups of samples, mean values were recalculated in Excel to cross-check data filtering and calculations made in R). All calculations made in Excel spreadsheets (i.e., calculation of predicted concentrations) underwent QAQC review.



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Appendix A: Maps, Figures, and Tables showing PCB Concentration Data
(Includes Electronic Files)



APPENDIX A MAP INDEX

Map 1:	Map of Spokane River mile markers
Map 2:	Map of fish sample stations by study ID on the Spokane River - study date range 1992-2016
Map 3:	Map of surface sediment sample stations by study ID on the Spokane River - study date range 1990-2018
Map 4:	Map of surface sediment sample stations by study ID on the Spokane River - study date range 2003-2016
Map 5:	Map of water sample stations by study ID on the Spokane River - study date range 2000-2018
Map 6:	Map of suspended sediment sample stations by study ID on the Spokane River - study date range 2003-2017
Map 7:	Map of biofilm and invertebrate sample stations by study ID on the Spokane River - 2018

APPENDIX A FIGURES INDEX

Figure 1 Set

Figure 1A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by species (all) and year. Non-detects assigned zero.

Figure 1B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by species (all) and year. Non-detects assigned half DL.

Figure 1C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by species (all) and year. Non-detects assigned full DL.

Figure 1D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by species (all) and year. Non-detects assigned zero.

Figure 1E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by species (all) and year. Non-detects assigned half DL.

Figure 1F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by species (all) and year. Non-detects assigned full DL.

Figure 2 Set

Figure 2A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned zero.



Figure 2B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned half DL.

Figure 2C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned full DL.

Figure 2D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned zero.

Figure 2E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned half DL.

Figure 2F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by the main species and year, other species are grouped together. Non-detects assigned full DL.

Figure 3 Set

Figure 3A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by species (all) and river stretch. Non-detects assigned zero.

Figure 3B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by species (all) and river stretch. Non-detects assigned half DL.

Figure 3C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by species (all) and river stretch. Non-detects assigned full DL.

Figure 3D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by species (all) and river stretch. Non-detects assigned zero.

Figure 3E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by species (all) and river stretch. Non-detects assigned half DL.

Figure 3F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by species (all) and river stretch. Non-detects assigned full DL.

Figure 4 Set

Figure 4A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned zero.

Figure 4B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned half DL.



Figure 4C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned full DL.

Figure 4D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned zero.

Figure 4E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned half DL.

Figure 4F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned full DL.

Figure 5 Set

Figure 5A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

Figure 5B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 5C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

Figure 5D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

Figure 5E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 5F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

Figure 6 Set

Figure 6A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.



Figure 6B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 6C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

Figure 6D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

Figure 6E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 6F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

Figure 7 Set

Figure 7A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

Figure 7B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 7C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

Figure 7D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

Figure 7E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

Figure 7F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.



Figure 8 Set

Figure 8A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned zero.

Figure 8B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned half DL.

Figure 8C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned full DL.

Figure 8D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned zero.

Figure 8E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned half DL.

Figure 8F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned full DL.

Figure 9: Total PCB 3xblank censored concentrations in surface water from the Spokane River (ng/L) as a function of River Mile. Subset by year, showing all detection limit treatments.

Figure 10: Total PCB 3xblank censored concentrations in surface water from the Spokane River (ng/L) as a function of year. Subset by river stretch, showing all detection limit treatments.

Figure 11 Set

Figure 11A: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg dry weight) as a function of River Mile. Subset by year, showing all detection limit treatments.

Figure 11B: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg OC) as a function of River Mile. Subset by year, showing all detection limit treatments.

Figure 12 Set

Figure 12A: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch, showing all detection limit treatments.



Figure 12B: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch, showing all detection limit treatments.

Figure 13 Set

Figure 13A: Total PCB concentrations in biofilm and invertebrates from the Spokane River (ng/kg wet weight) as a function of River Mile. Subset by year, showing all detection limit treatments.

Figure 13B: Total PCB concentrations in biofilm and invertebrates from the Spokane River (ng/kg lipid) as a function of River Mile. Subset by year, showing all detection limit treatments.

Figure 13C: Total PCB concentrations in biofilm from the Spokane River (ng/kg OC) as a function of River Mile. Subset by year, showing all detection limit treatments.

APPENDIX A ELECTRONIC DATA TABLES INDEX

01_PCB Concentration Tables 09Oct19.xlsm

Table 1: Station identification labels and location details for fish collected from the Spokane River and analyzed for PCBs.

Table 2: Summary of total PCB concentrations in fish from the Spokane River based on Aroclor and congener data - wet weight (ng/kg ww), lipid normalized (ng/kg lipid), number of PCB analytes and non-detects and lipid contents (%).

Table 3: Summary of total PCB concentrations in fish from the Spokane River based on Aroclor and congener data pooled across analysis type - wet weight (ng/kg ww), lipid normalized (ng/kg lipid), and lipid contents (%).

Table 4: Station identification labels and location details for surface sediment samples collected from the Spokane River and analyzed for PCBs.

Table 5: Summary of total PCB concentrations in surface sediment from the Spokane River - dry weight (ng/kg dw), organic carbon normalized (ng/kg TOC), number of PCB analytes and non-detects, total organic carbon contents (TOC, %), and total solids (TS, %).

Table 6: Summary of total PCB concentrations in surface sediment from the Spokane River pooled across analysis type - dry weight (ng/kg dw), organic carbon normalized (ng/kg TOC), total organic carbon contents (TOC, %) and total solids (TS, %).

Table 7: Station identification labels and location details for freshwater samples collected from the Spokane River and analyzed for PCBs.



Table 8: Summary of total PCB concentrations in freshwater from the Spokane River - 3xblank censored⁶ (ng/L), number of PCB analytes and non-detects, total organic carbon (TOC, mg/L), total suspended solids (TSS, mg/L), total dissolved solids (TDS, mg/L), and dissolved organic carbon (DOC, mg/L).

Table 9: Station identification labels and location details for suspended sediment samples collected from the Spokane River and analyzed for PCBs.

Table 10: Summary of total PCB concentrations in suspended sediments from the Spokane River - dry weight (ng/kg dw), organic carbon normalized (ng/kg TOC), number of PCB analytes and non-detects, total organic carbon contents (TOC, %), moisture content (%) and total solids (TS, %).

Table 11: Station identification labels and location details for biofilm and invertebrate samples collected from the Spokane River and analyzed for PCBs.

Table 12: Summary of total PCB concentrations in biofilm and invertebrate samples from the Spokane River - wet weight (ng/kg ww), lipid normalized (ng/kg lipid), organic carbon normalized (ng/kg OC), number of PCB analytes and non-detects, lipid contents (%) and total organic carbon contents (TOC, %).

02_Future Fish PCB Predictions w RA 30Sep19.xlsx

Table 1: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the baseline time period (2001-2005). No pooling across analysis type.

Table 2: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the baseline time period (2001-2005). Pooled across analysis type.

Table 3: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the 2012* time period, and six scenarios predicted for the future time period (2030). No pooling across analysis type. *Also includes 2014 PCB concentration data in Common Carp; this is considered to represent the "current" time period.

Table 4: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the 2012* time period, and six scenarios predicted for the future time period (2030). Pooled across analysis type. *Also includes 2014 PCB concentration data in Common Carp; this is considered to represent the "current" time period.

Table 5: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the 2012 time period, and lower and upper predictions for the current time period (2018)*. No pooling across analysis type. *Also includes 2014 PCB concentration data in Common Carp; this is considered to represent the "current" time period.

Table 6: Summary of total PCB concentrations - wet weight (ng/kg ww) and lipid normalized (ng/kg lipid), for fish from the Spokane River, for the 2012 time period, and lower and upper predictions for the current time period (2018)*. Pooled across analysis type. *Also includes 2014 PCB concentration data in Common Carp; this is considered to represent the "current" time period.



Table 7: Summary of arithmetic and geometric mean total PCB concentrations - wet weight (ng/kg ww) for fish from the Spokane River, based on six scenarios for the future time period (2030). No pooling across analysis type.

Table 8: Summary of arithmetic and geometric mean total PCB concentrations - wet weight (ng/kg ww) for fish from the Spokane River, based on six scenarios for the future time period (2030). Pooled across analysis type.

Table 9: Summary of arithmetic and geometric mean total PCB concentrations - wet weight (ng/kg ww) for fish from the Spokane River, for lower and upper bound predictions for the current time period (2018). No pooling across analysis type.

Table 10: Summary of arithmetic and geometric mean total PCB concentrations - wet weight (ng/kg ww) for fish from the Spokane River, for lower and upper bound predictions for the current time period (2018). Pooled across analysis type.

Table 11: Summary of arithmetic mean total PCB concentrations - wet weight (ng/kg ww) and lipid weight (ng/kg lipid) for fish from the Spokane River: 2012 data and six scenarios for the future time period (2030). No pooling across analysis type.

Table 12: Summary of arithmetic mean total PCB concentrations - wet weight (ng/kg ww) and lipid weight (ng/kg lipid) for fish from the Spokane River: 2012 data and lower and upper predictions for the current time period (2018). No pooling across analysis type.

03_Fish Predictions for RA_30Sept19.xlsx

Table 11: Summary of arithmetic mean total PCB concentrations - wet weight (ng/kg ww) and lipid weight (ng/kg lipid) for fish from the Spokane River: 2012 data and six scenarios for the future time period (2030). No pooling across analysis type.

Table 12: Summary of arithmetic mean total PCB concentrations - wet weight (ng/kg ww) and lipid weight (ng/kg lipid) for fish from the Spokane River: 2012 data and lower and upper predictions for the current time period (2018). No pooling across analysis type.

04_Future Sediment PCB Predictions 28Sept19.xlsx

Table 1: Summary of total PCB concentrations - dry weight (ng/kg dw) and organic carbon normalized (ng/kg TOC), for sediment from the Spokane River, for the baseline time period (2003-2004). No pooling across analysis type.



Table 2: Summary of total PCB concentrations - dry weight (ng/kg dw) and organic carbon normalized (ng/kg TOC), for sediment from the Spokane River, for the baseline time period (2003-2004). Pooled across analysis type.

Table 3: Summary of total PCB concentrations - dry weight (ng/kg dw) and organic carbon normalized (ng/kg TOC), for sediment from the Spokane River, for the current time period (2013-2018), and six scenarios predicted for the future time period (2030).

Table 4: Summary of arithmetic and geometric mean total PCB concentrations - dry weight (ng/kg dw) for sediment from the Spokane River, based on six scenarios for the future time period (2030).

05_Future Water PCB Predictions 28Sept19.xlsx

Table 1: Summary of total PCB concentrations (ng/L) for surface water from the Spokane River, for the baseline time period (2000-2003). No pooling across analysis type.

Table 2: Summary of total PCB concentrations (ng/L) for surface water from the Spokane River, for the current time period (2018 or most recent by river stretch), and six scenarios predicted for the future time period (2030).

Table 3: Summary of arithmetic and geometric mean total PCB concentrations (ng/L) for surface water from the Spokane River, based on six scenarios for the future time period (2030).

06_Risk Assessment Final Worksheet_Hypothetical Model 07Oct19.xlsx

Table 1: Percent loadings reductions⁽¹⁾ (%) between time periods or for future projections.

⁽¹⁾ *Values shown represent % reductions in PCB loadings and expected concentrations of PCBs in fish of the Spokane River between time periods; negative values are increases between time periods.*

Table 2: Predicted concentrations of PCBs in fish (ng/kg ww; arithmetic mean) from the Spokane River under different PCB loadings scenarios.



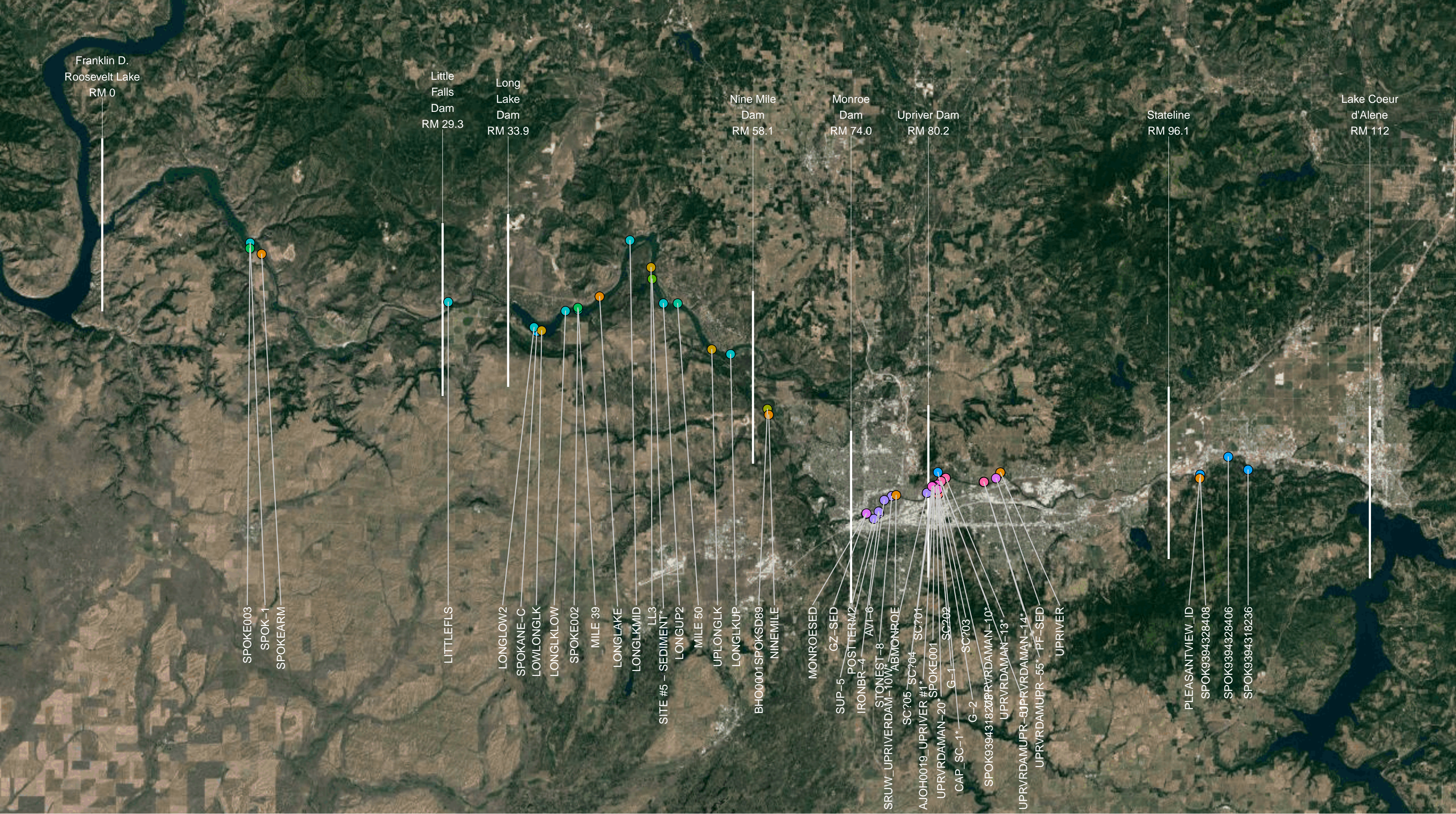
Map 1: Map of Spokane River mile markers



Map 2: Map of fish sample stations by study ID on the Spokane River - study date range 1992-2016



Map 3: Map of surface sediment sample stations by study ID on the Spokane River - study date range 1990 - 2018



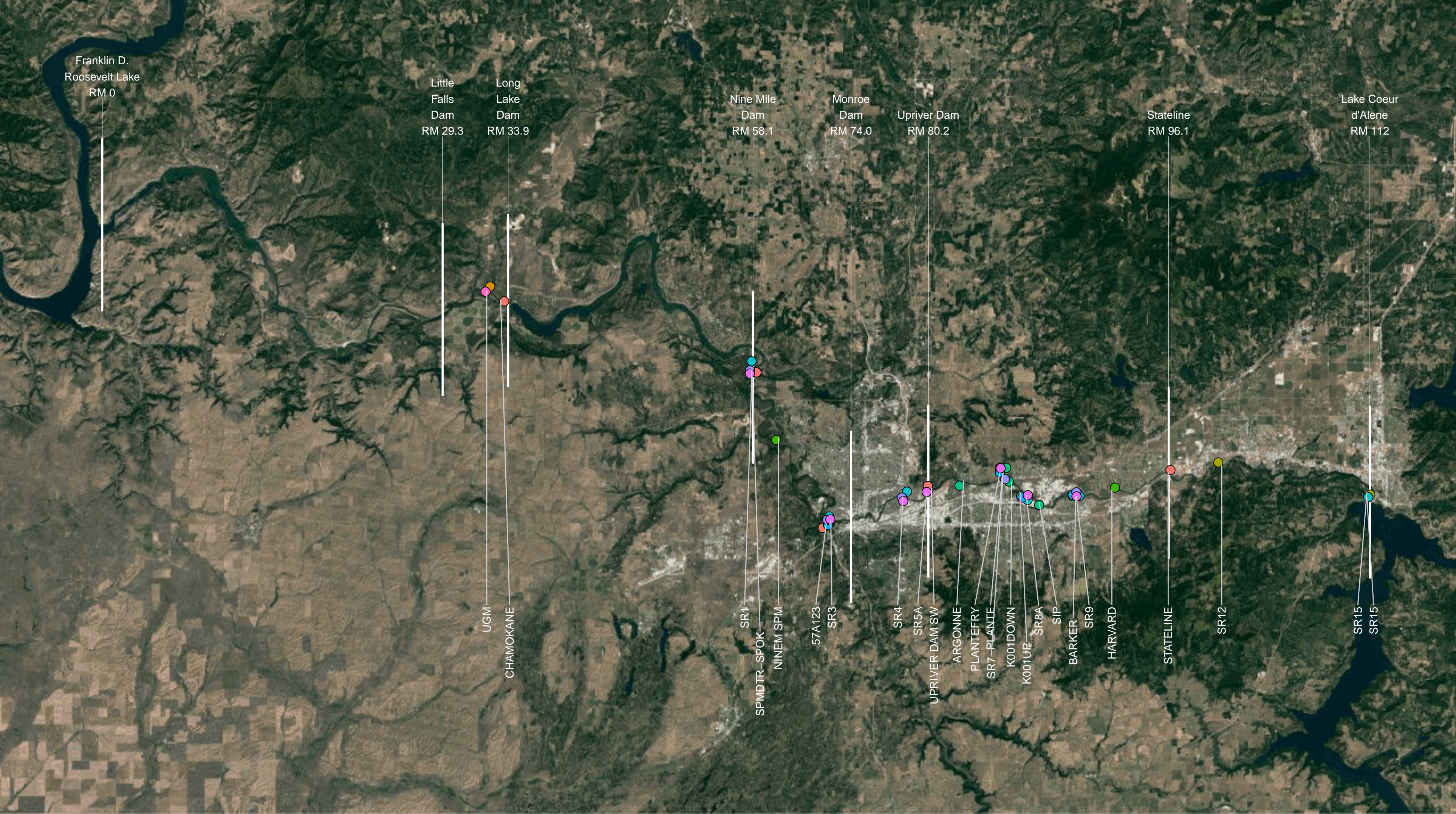
Map 4: Map of sub-surface sediment sample stations by study ID on the Spokane River - study date range 2003 - 2016



StudyID

- DSER0010
- SEDCORE16
- UPRVRDAM

Map 5: Map of water sample stations by study ID on the Spokane River - study date range 2000 - 2018



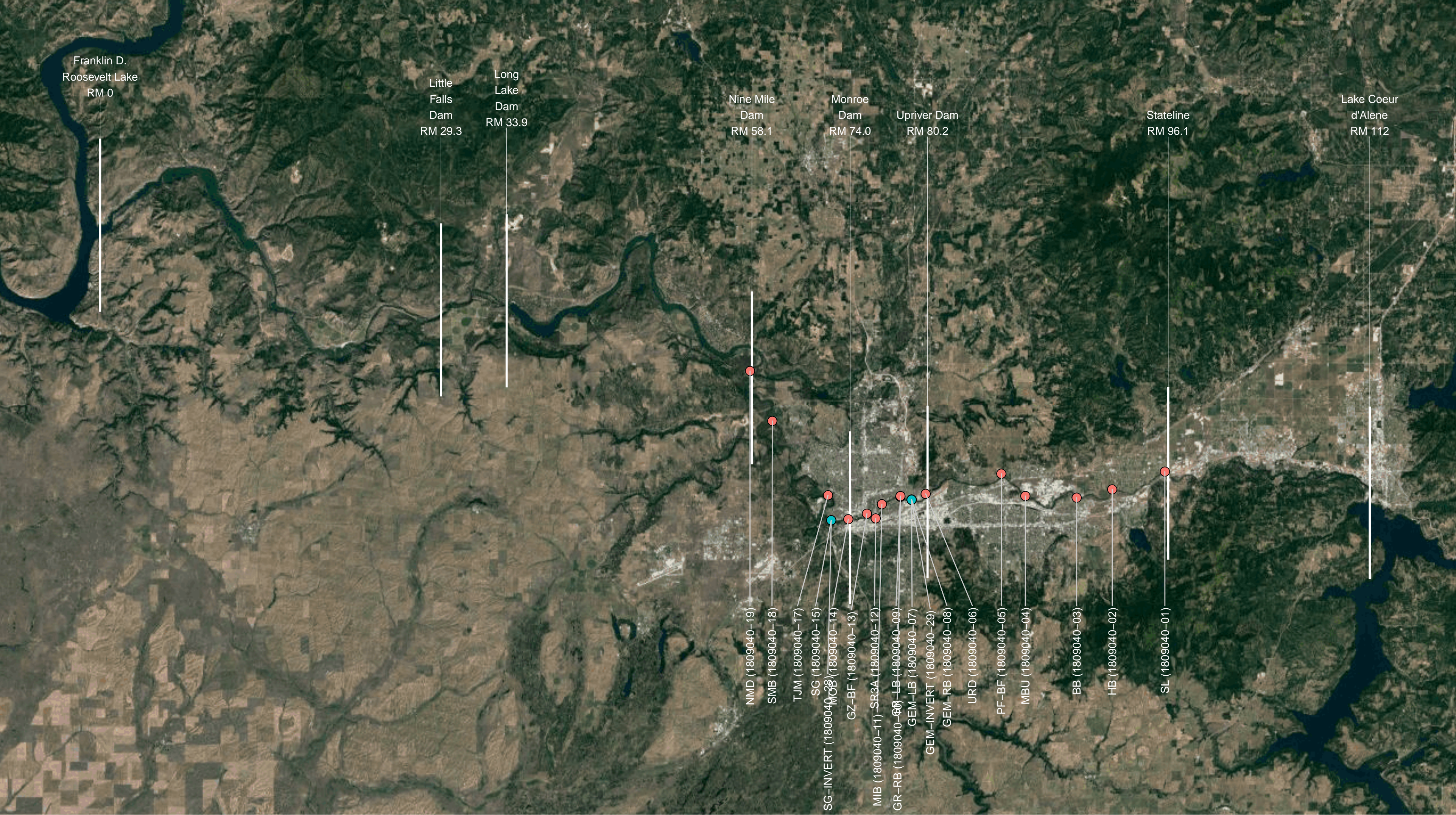
Map 6: Map of suspended sediment sample stations by study ID on the Spokane River - study date range 2003 - 2017



StudyID

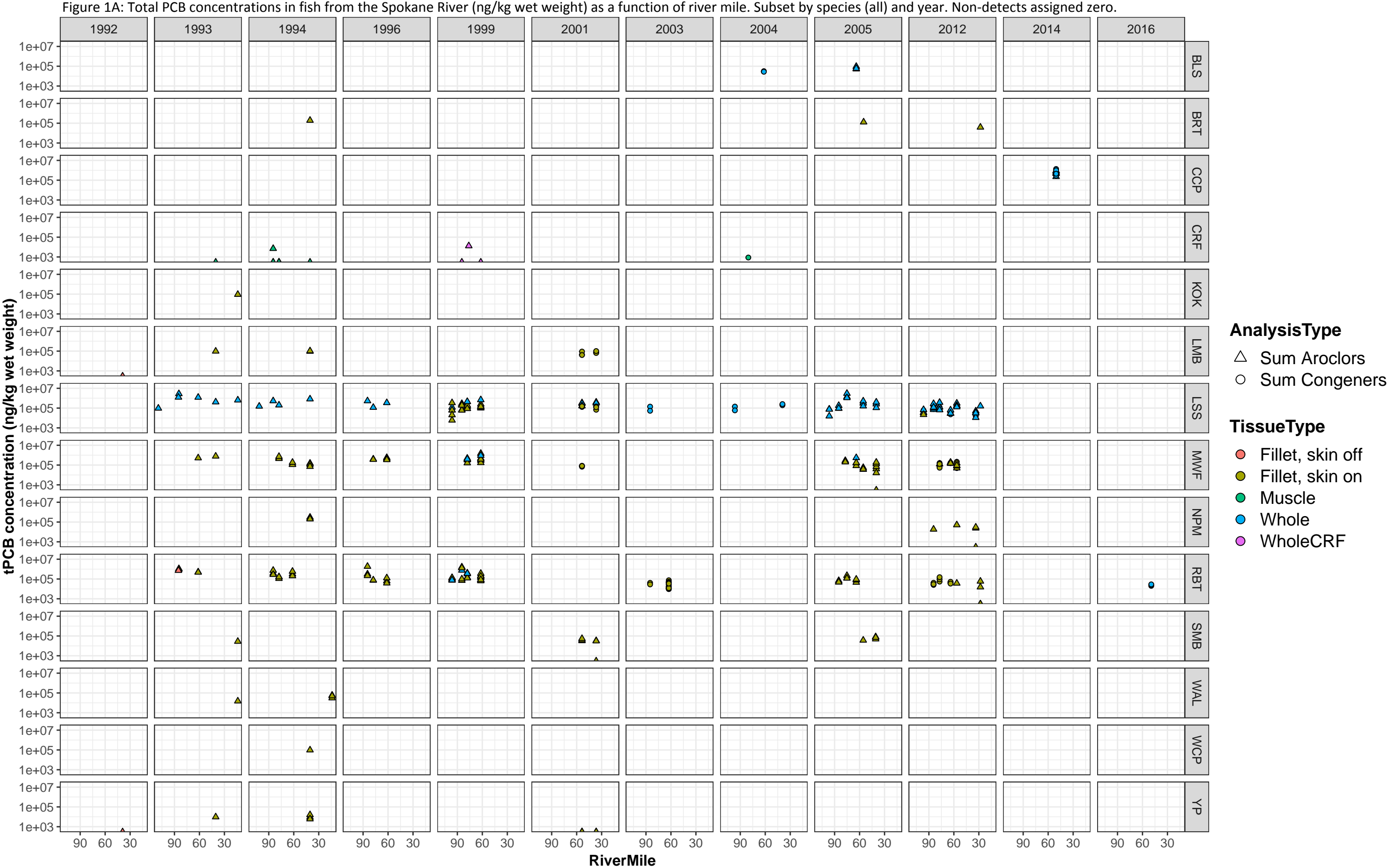
- BERA0009
- BERA0012
- DSER0010
- WHOB003

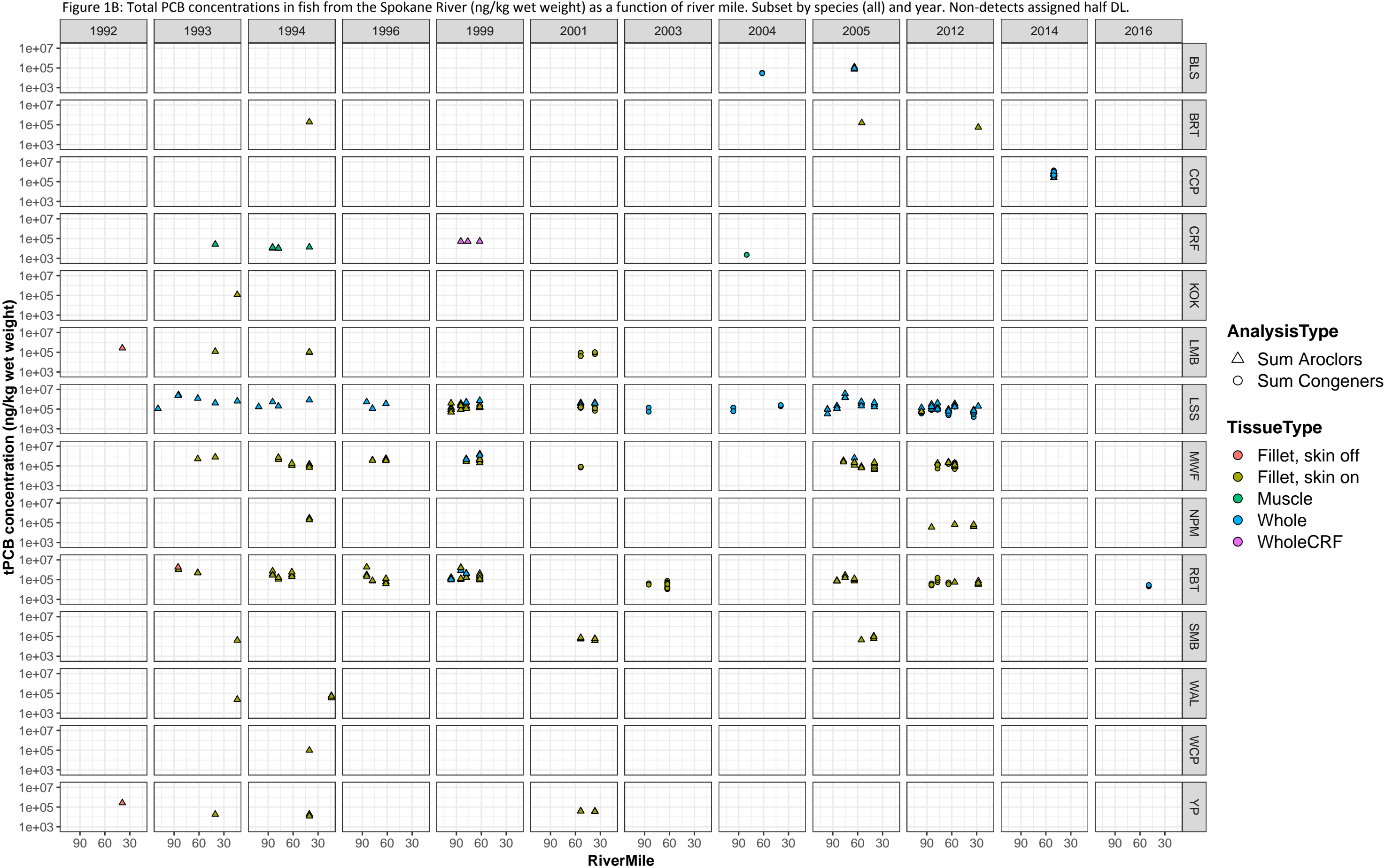
Map 7: Map of biofilm and invertebrate sample stations by study ID on the Spokane River - 2018

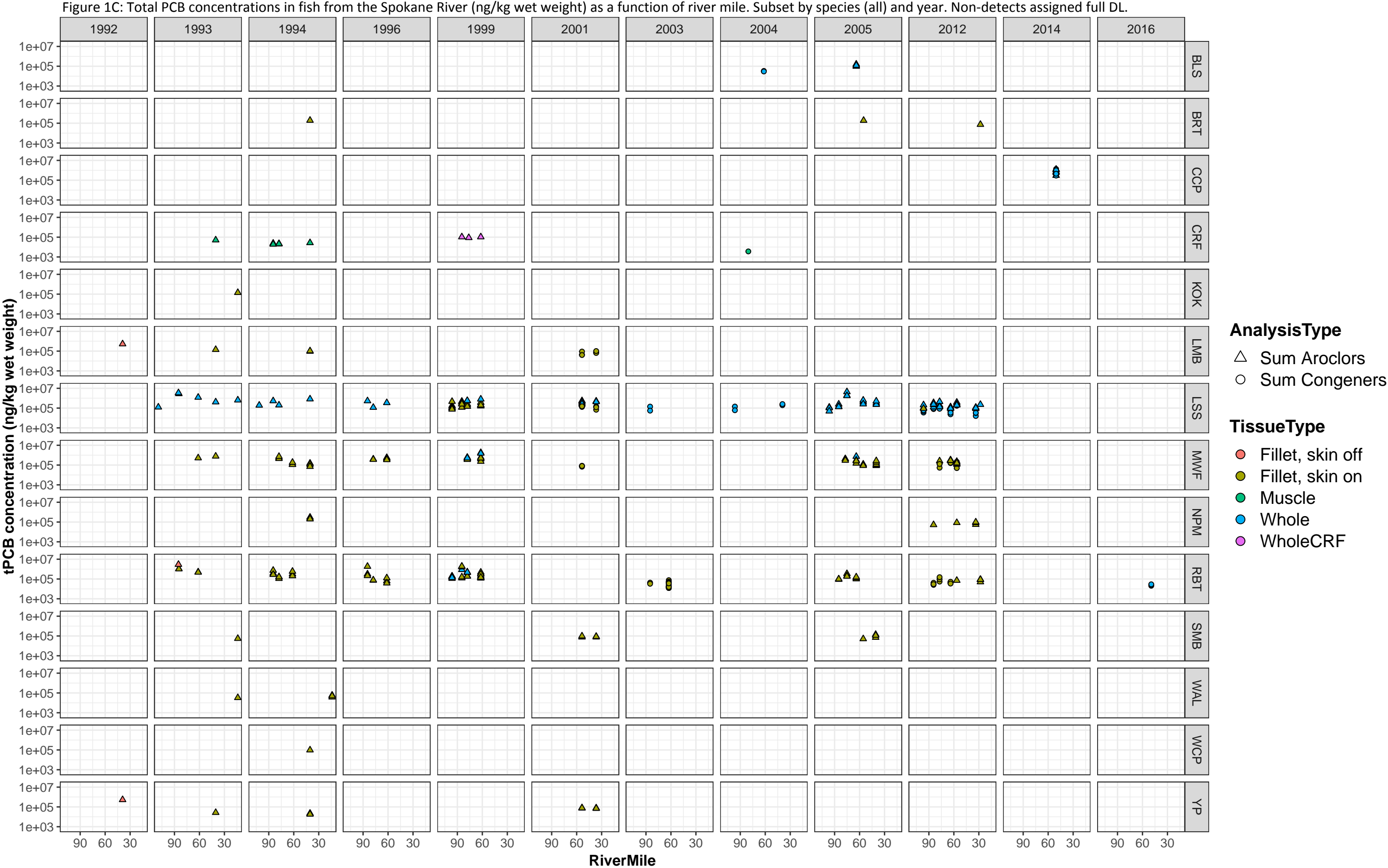


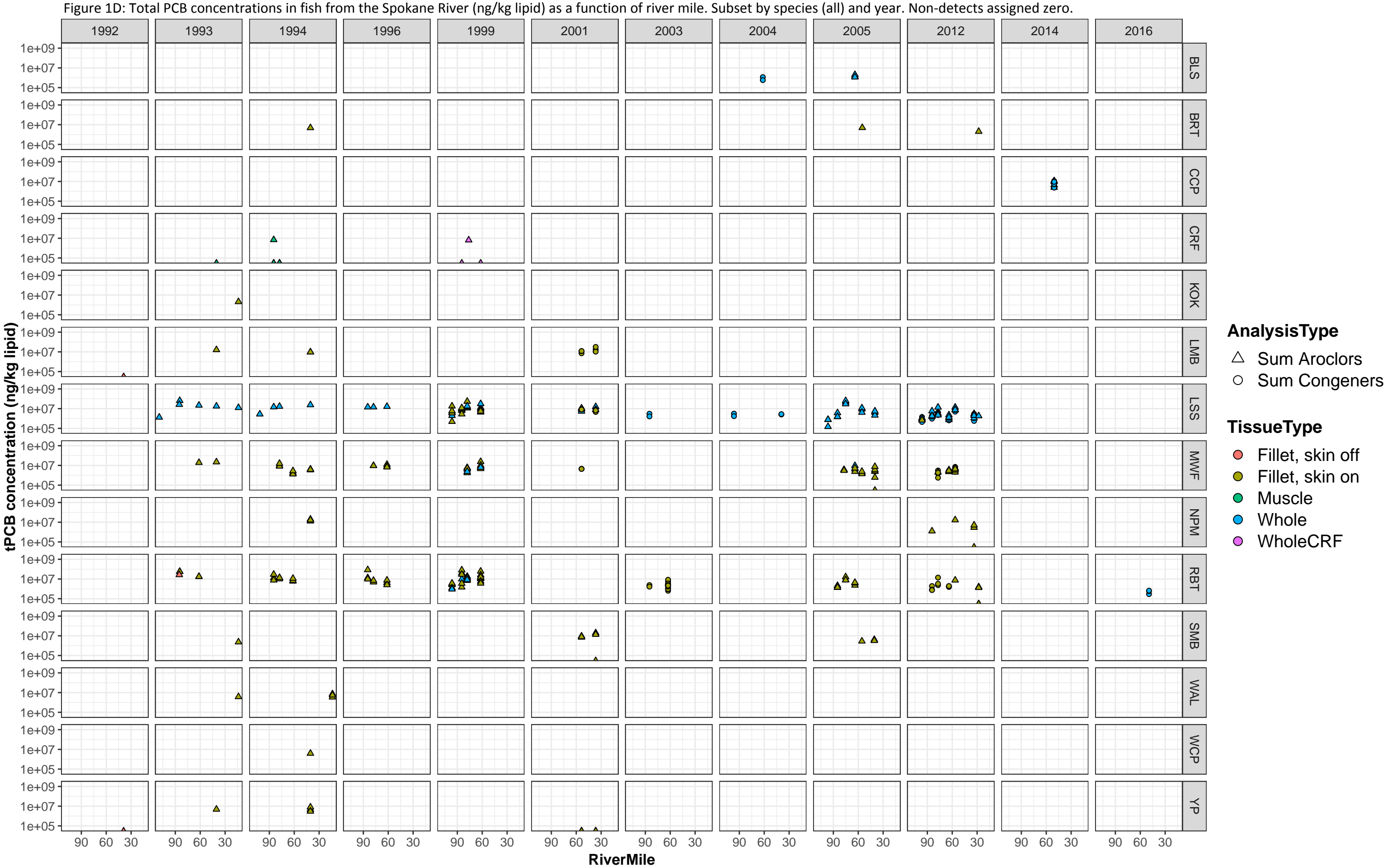
Sample Source

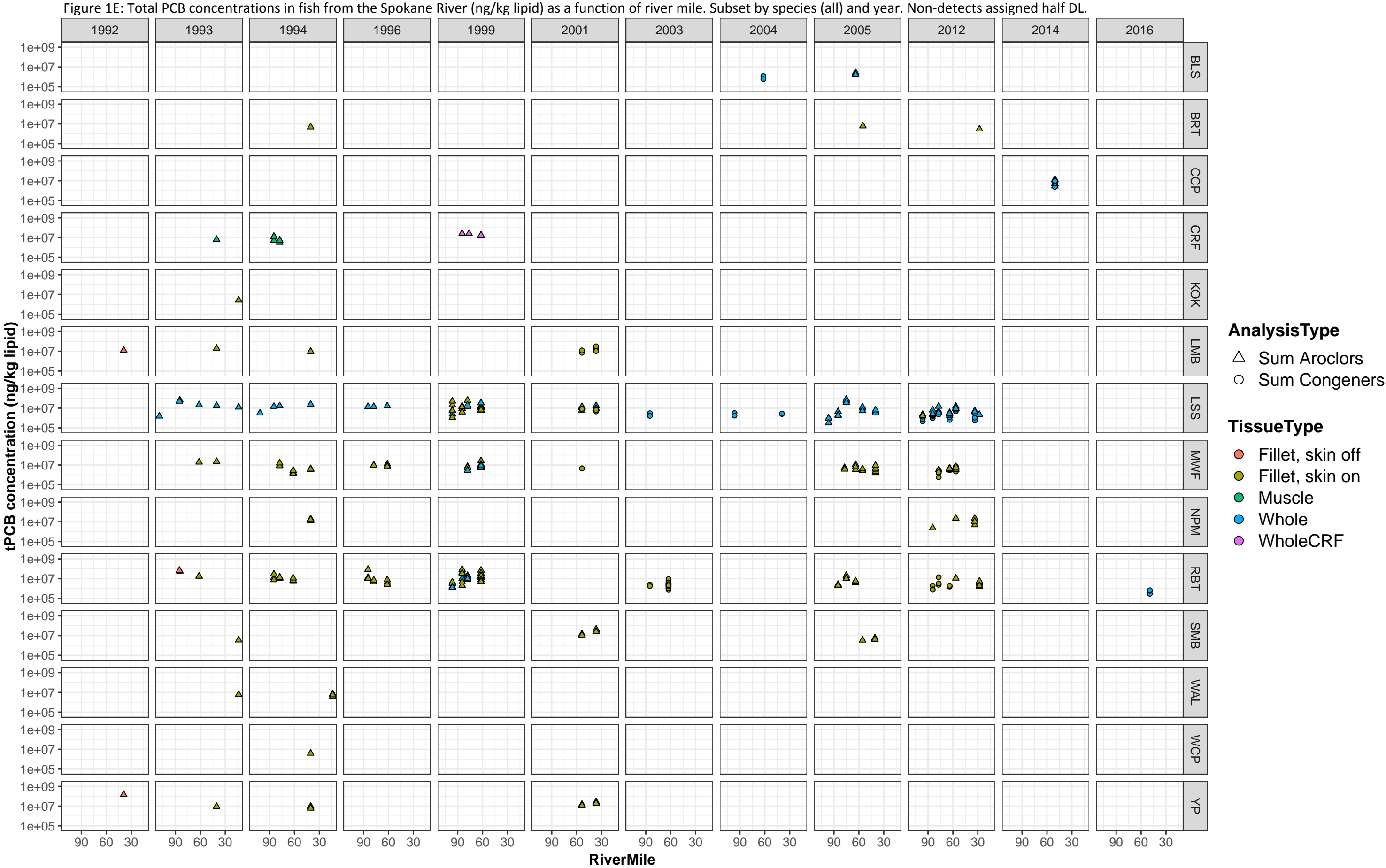
- Biofilm
- Invertebrate











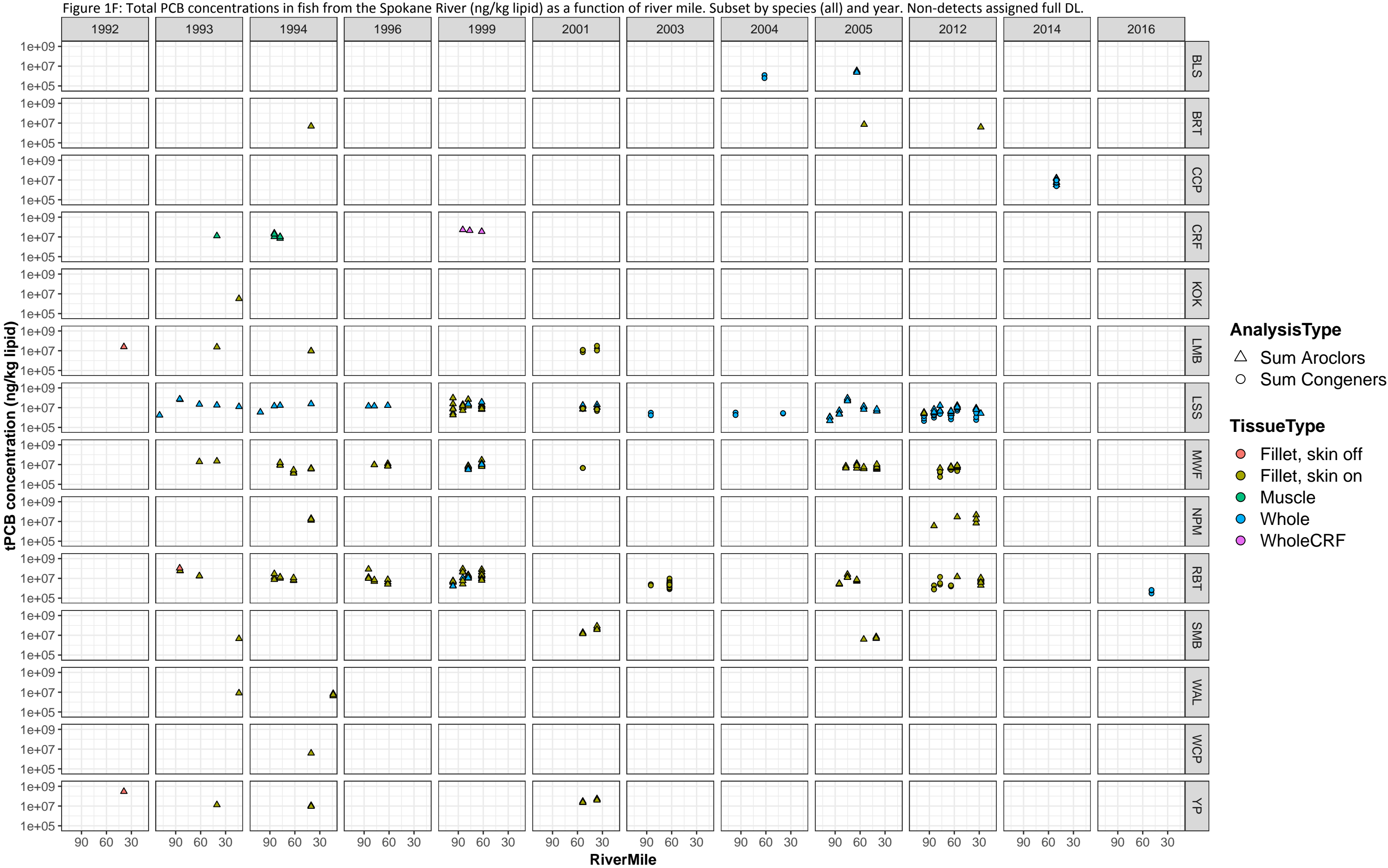


Figure 2A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of river mile. Subset by the main species and year, other species are grouped together.

Non-detects assigned zero.

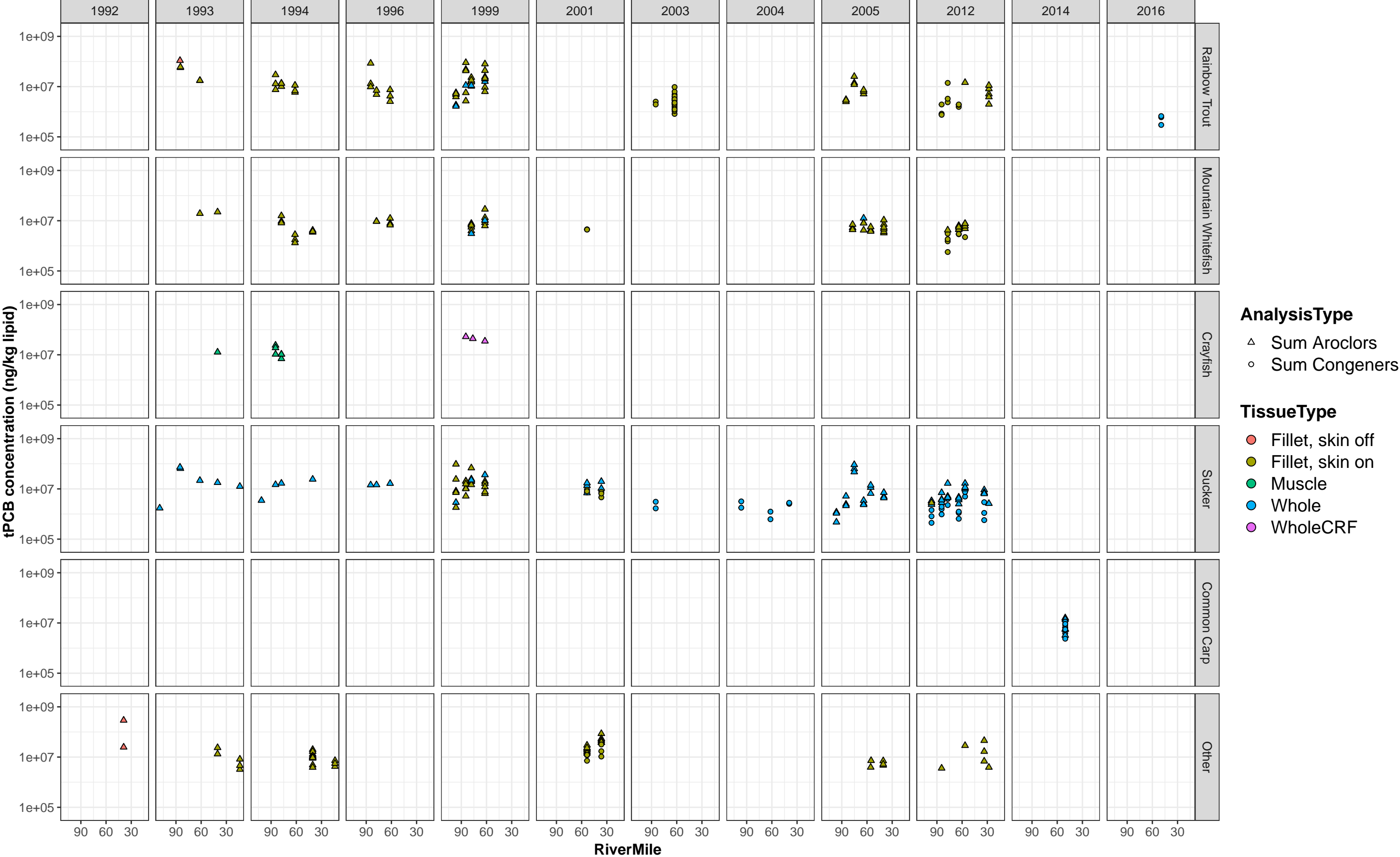


Figure 2B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of river mile. Subset by the main species and year, other species are grouped together.

Non-detects assigned half DL.

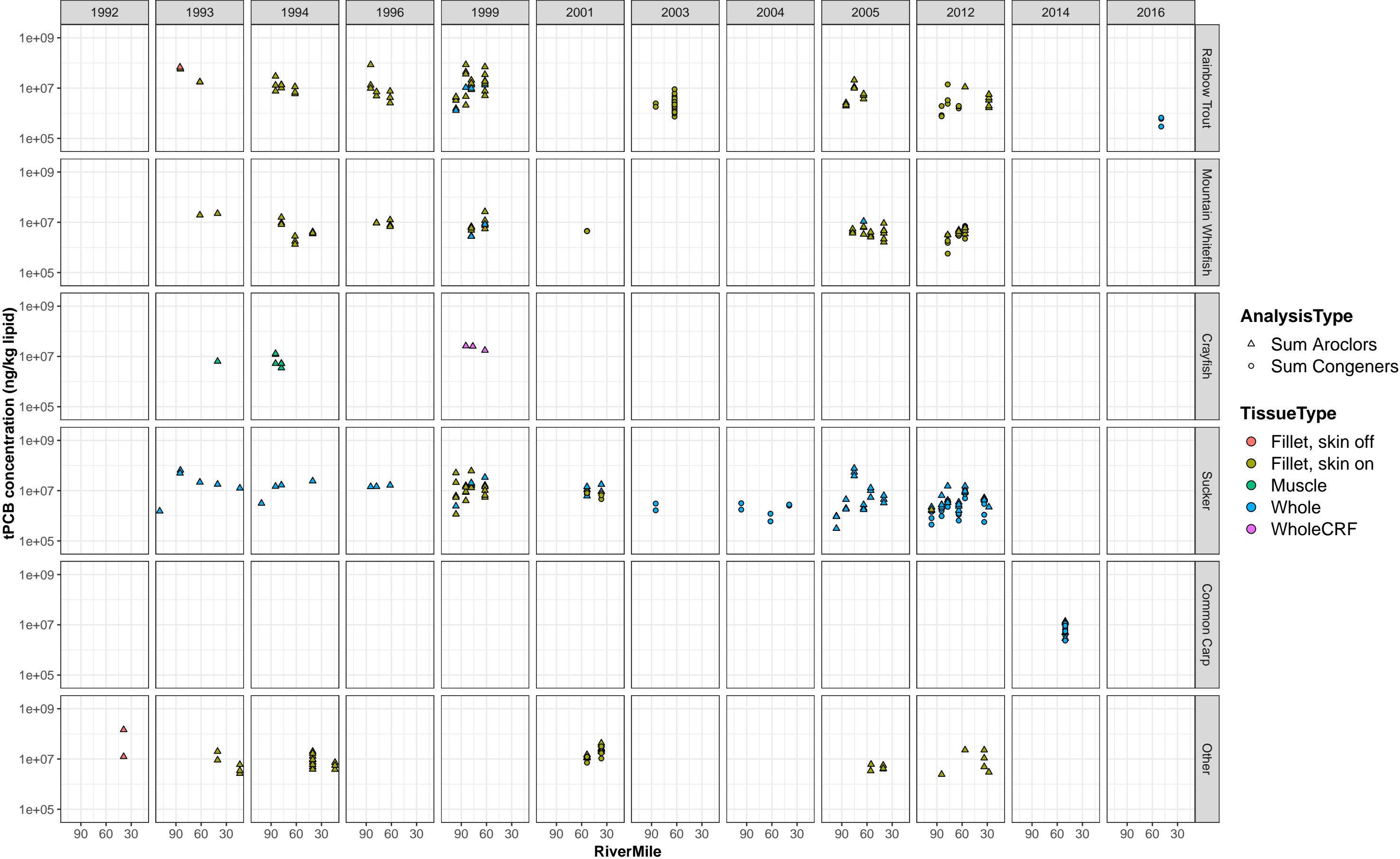


Figure 2C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of river mile. Subset by the main species and year, other species are grouped together.

Non-detects assigned full DL.

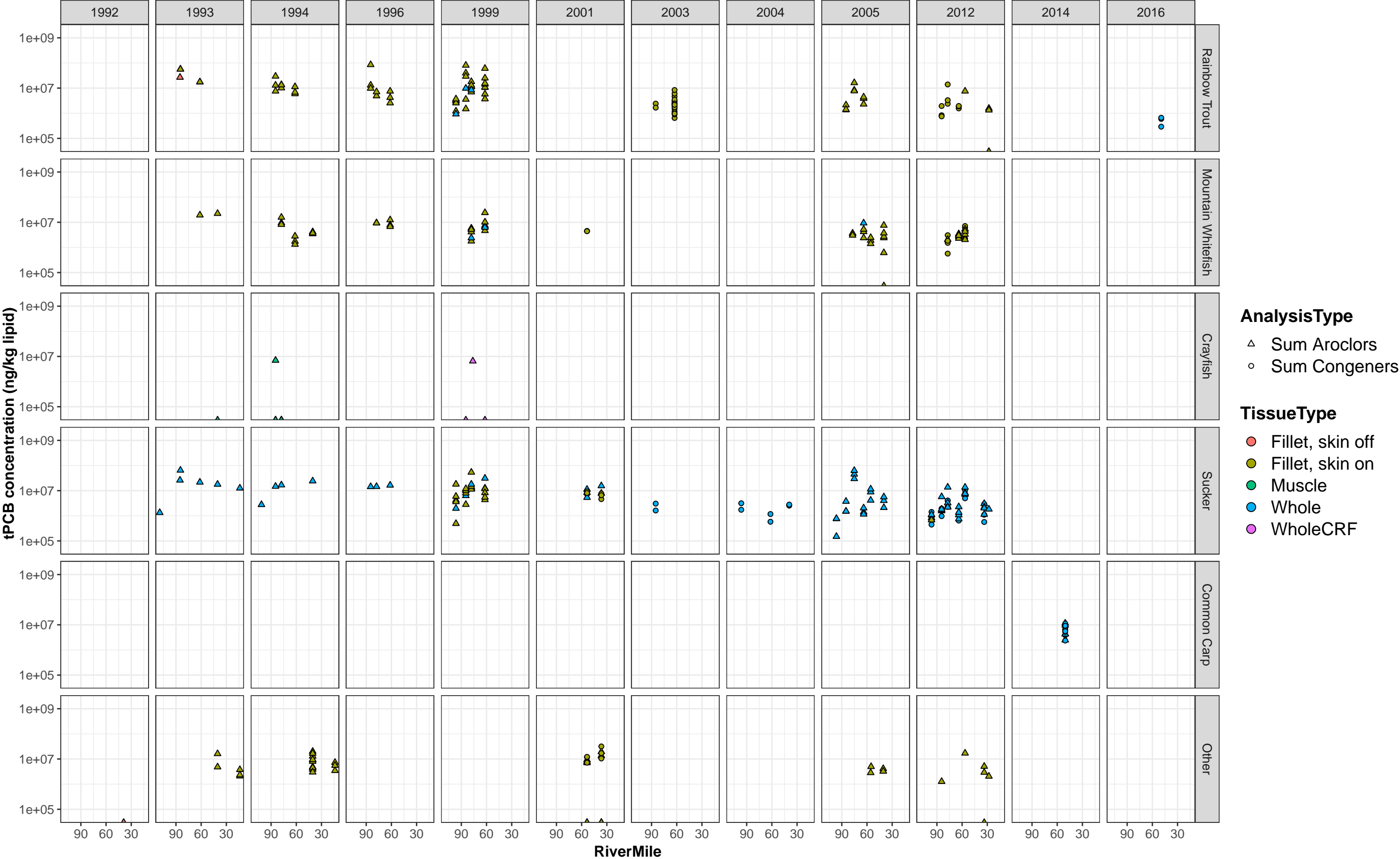


Figure 2D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of river mile. Subset by the main species and year, other species are grouped together.

Non-detects assigned zero.

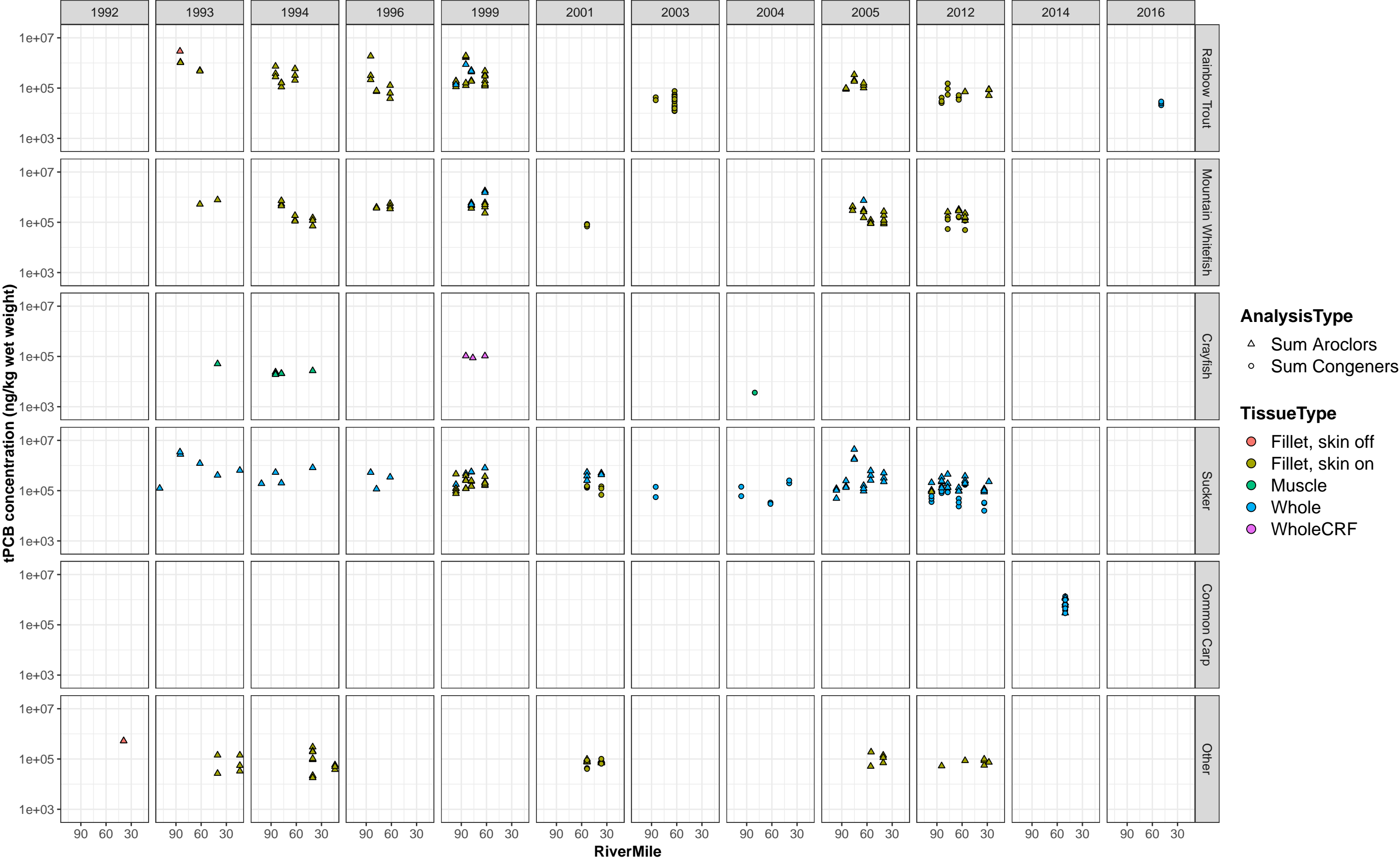


Figure 2E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of river mile. Subset by the main species and year, other species are grouped together.

Non-detects assigned half DL.

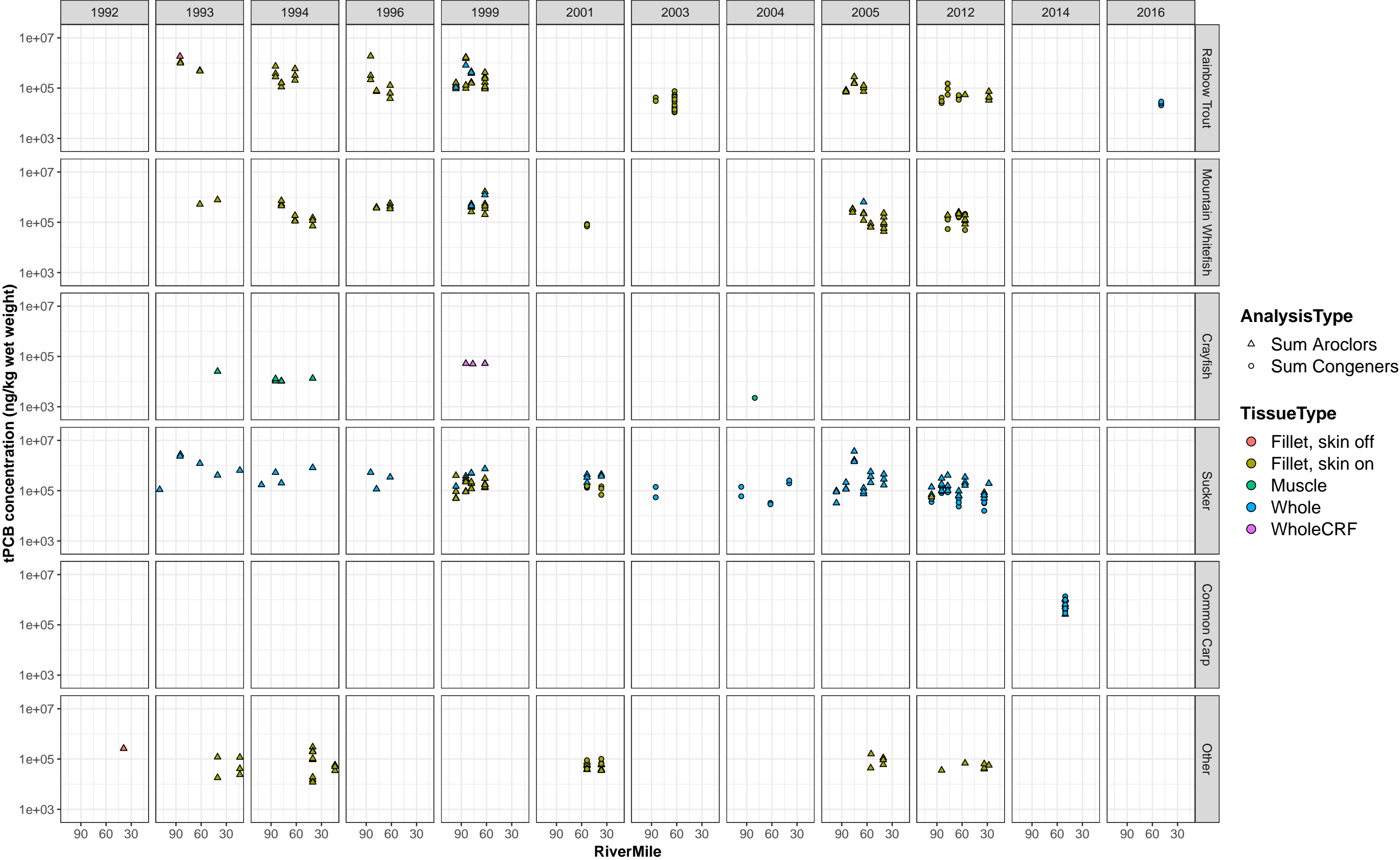
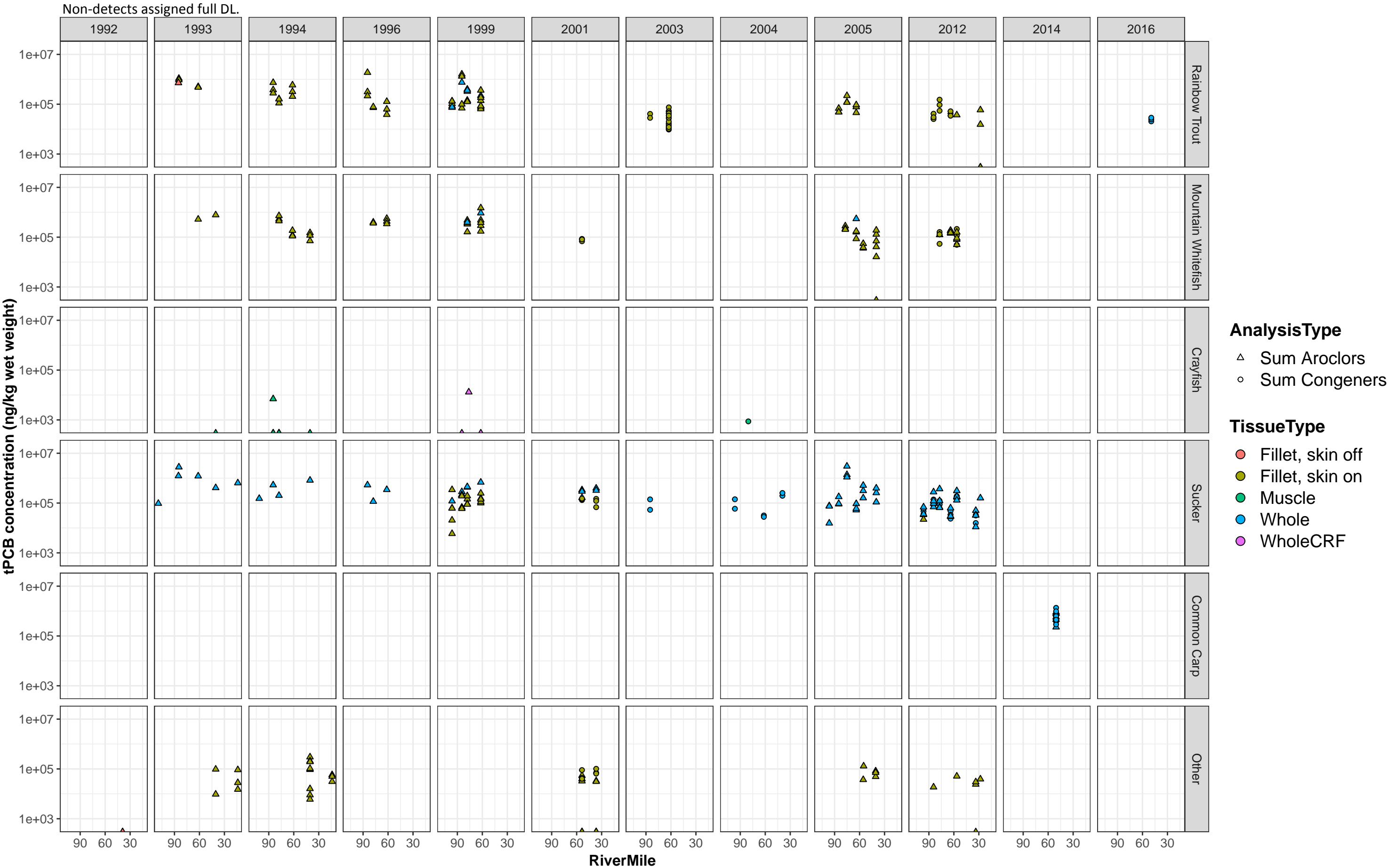
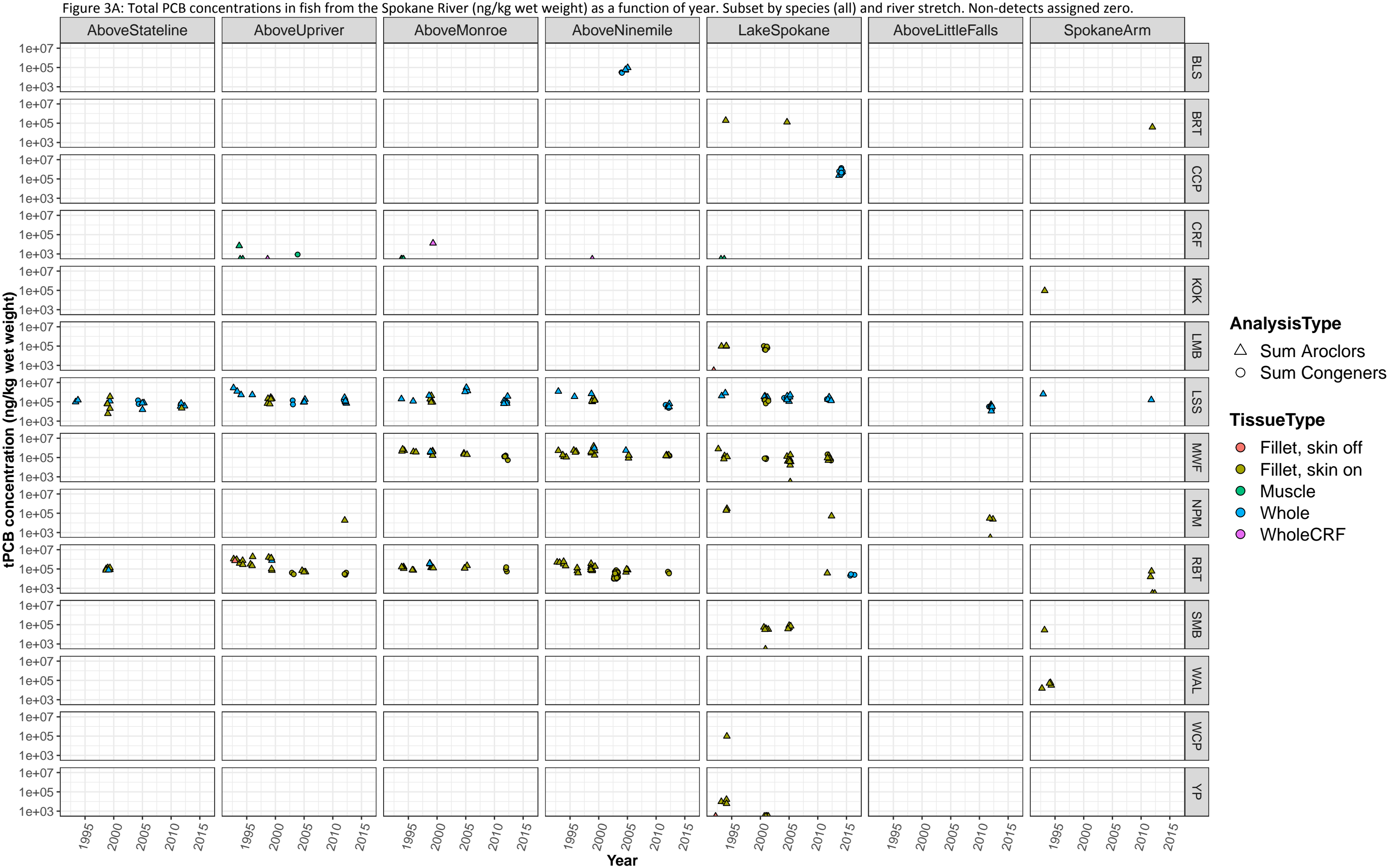
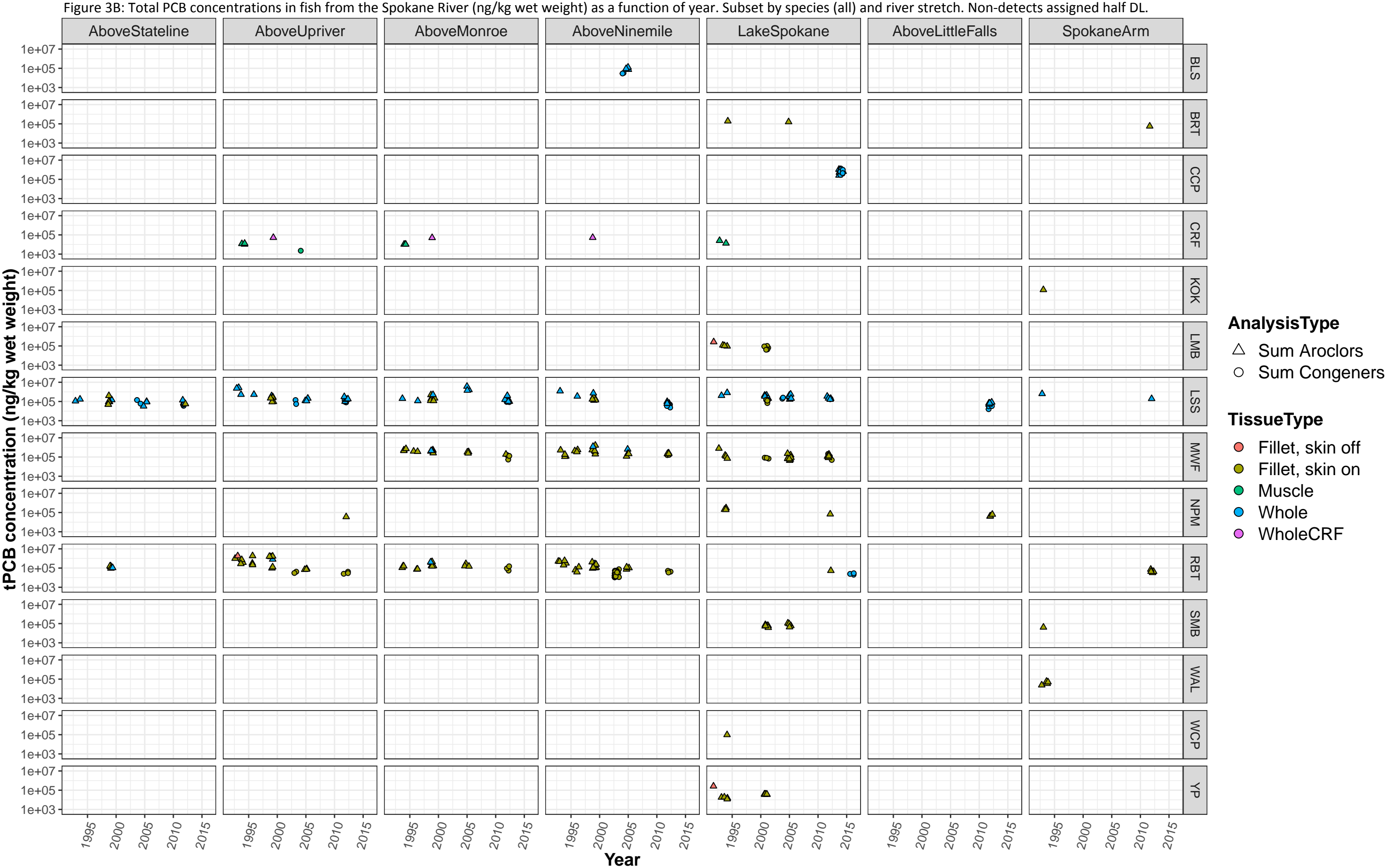
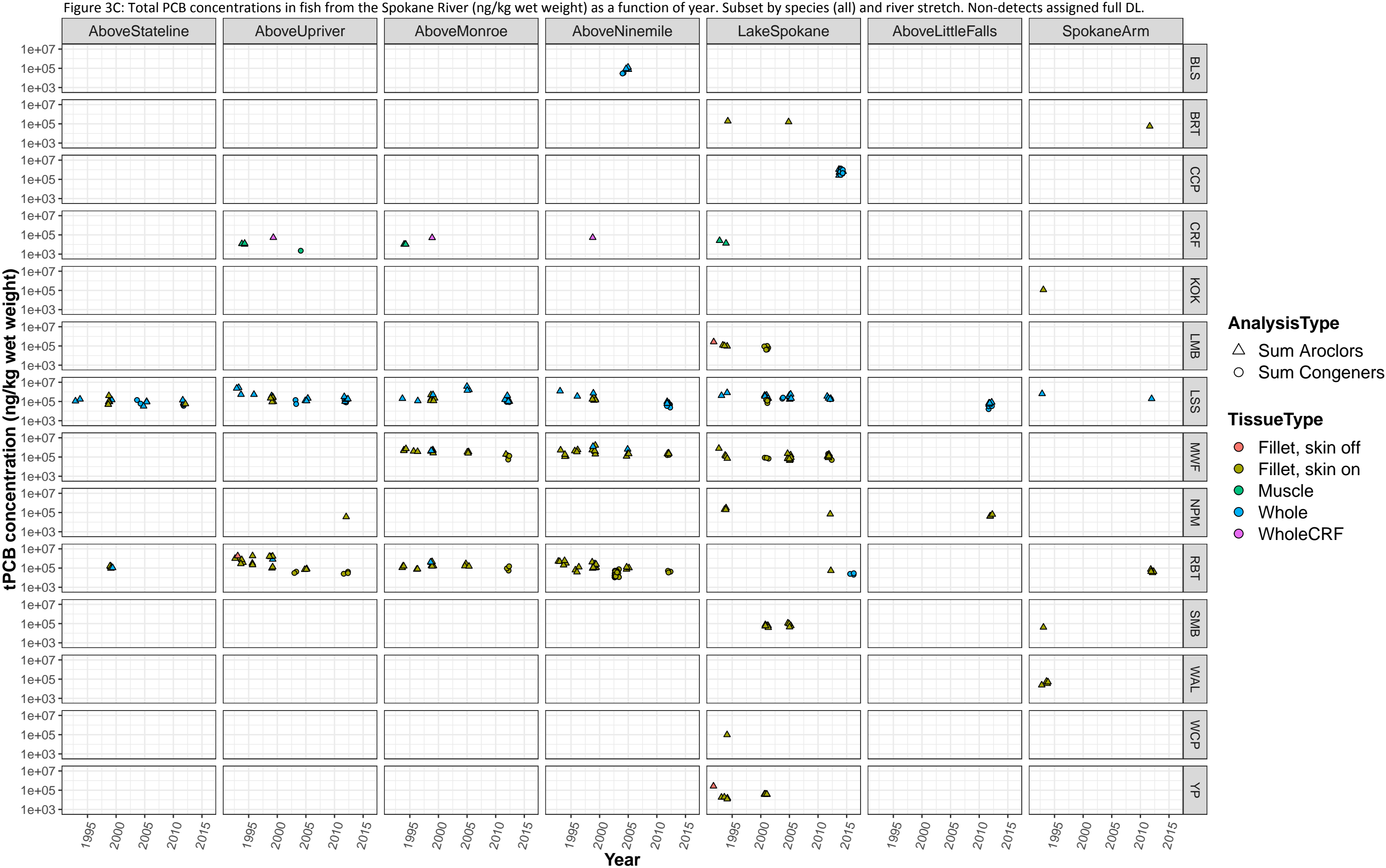


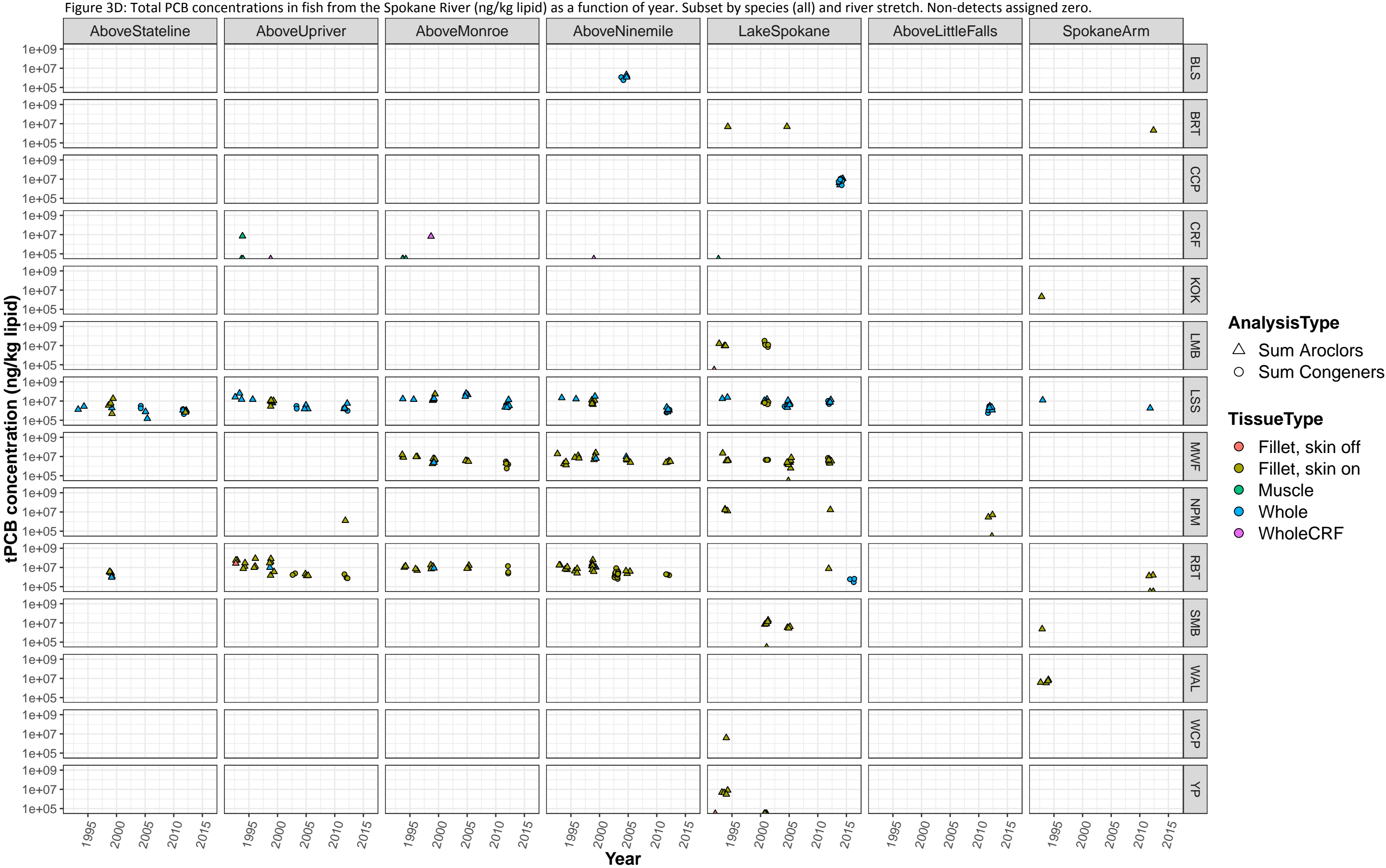
Figure 2F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of river mile. Subset by the main species and year, other species are grouped together.

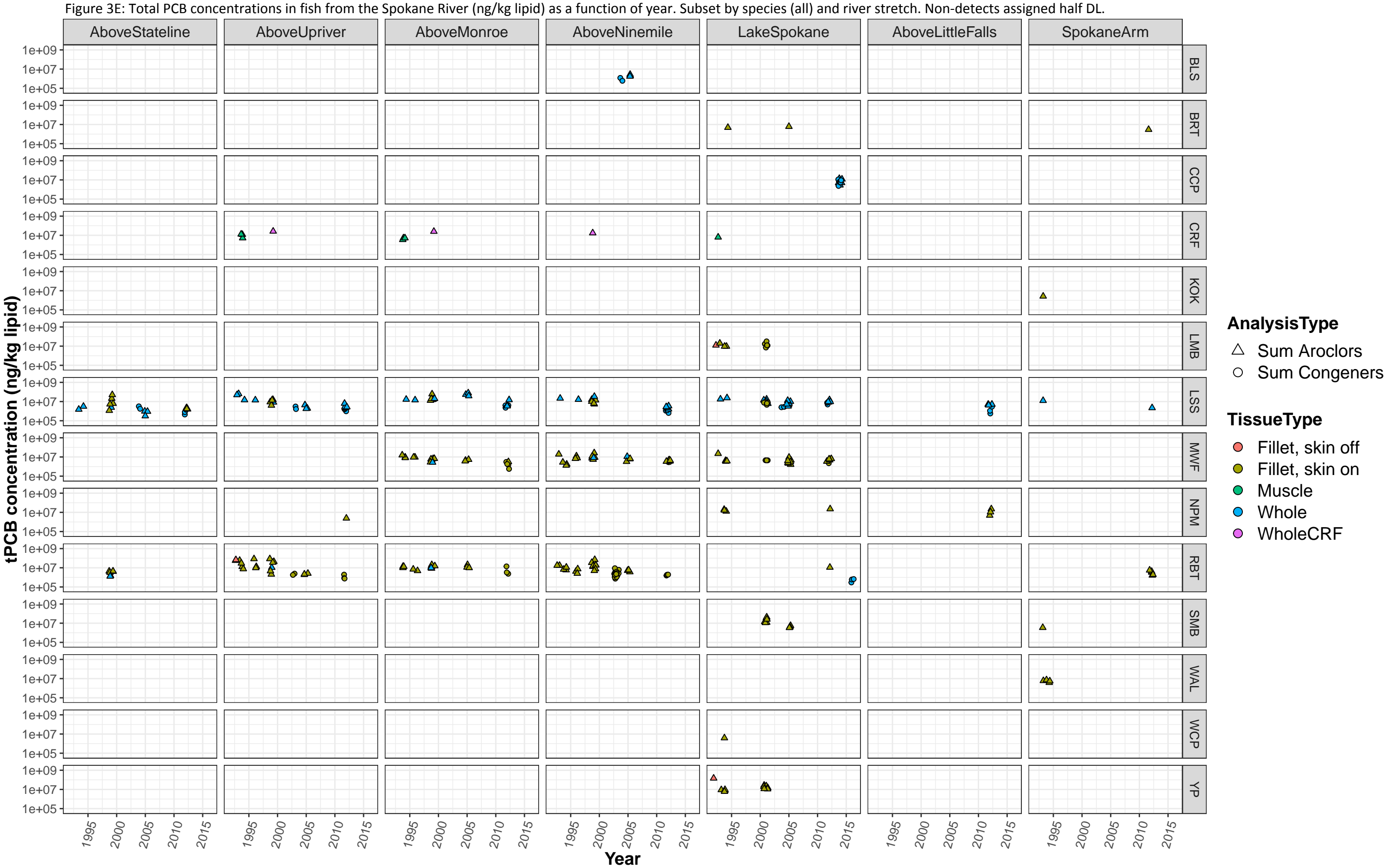












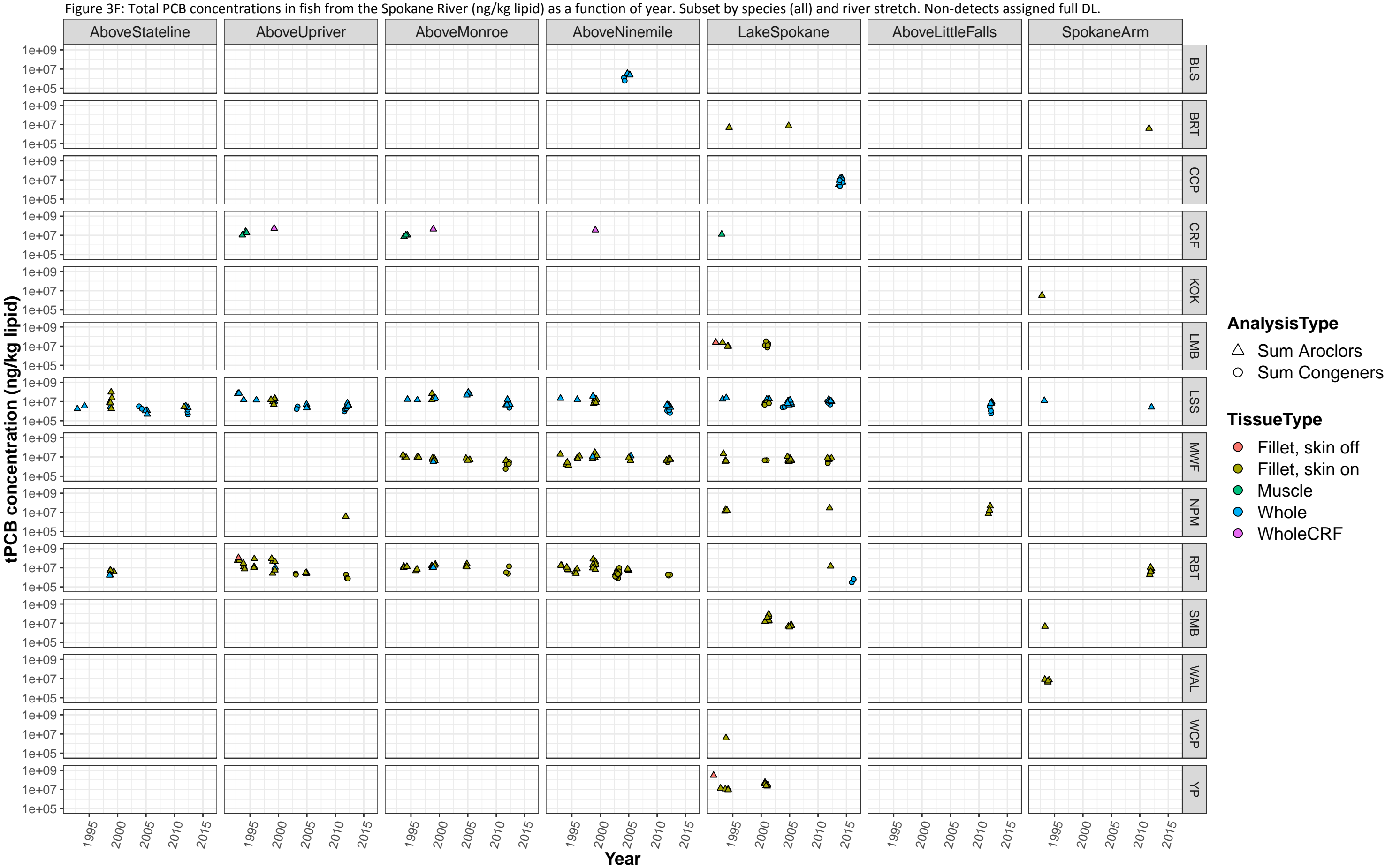


Figure 4A: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together.

Non-detects assigned zero.

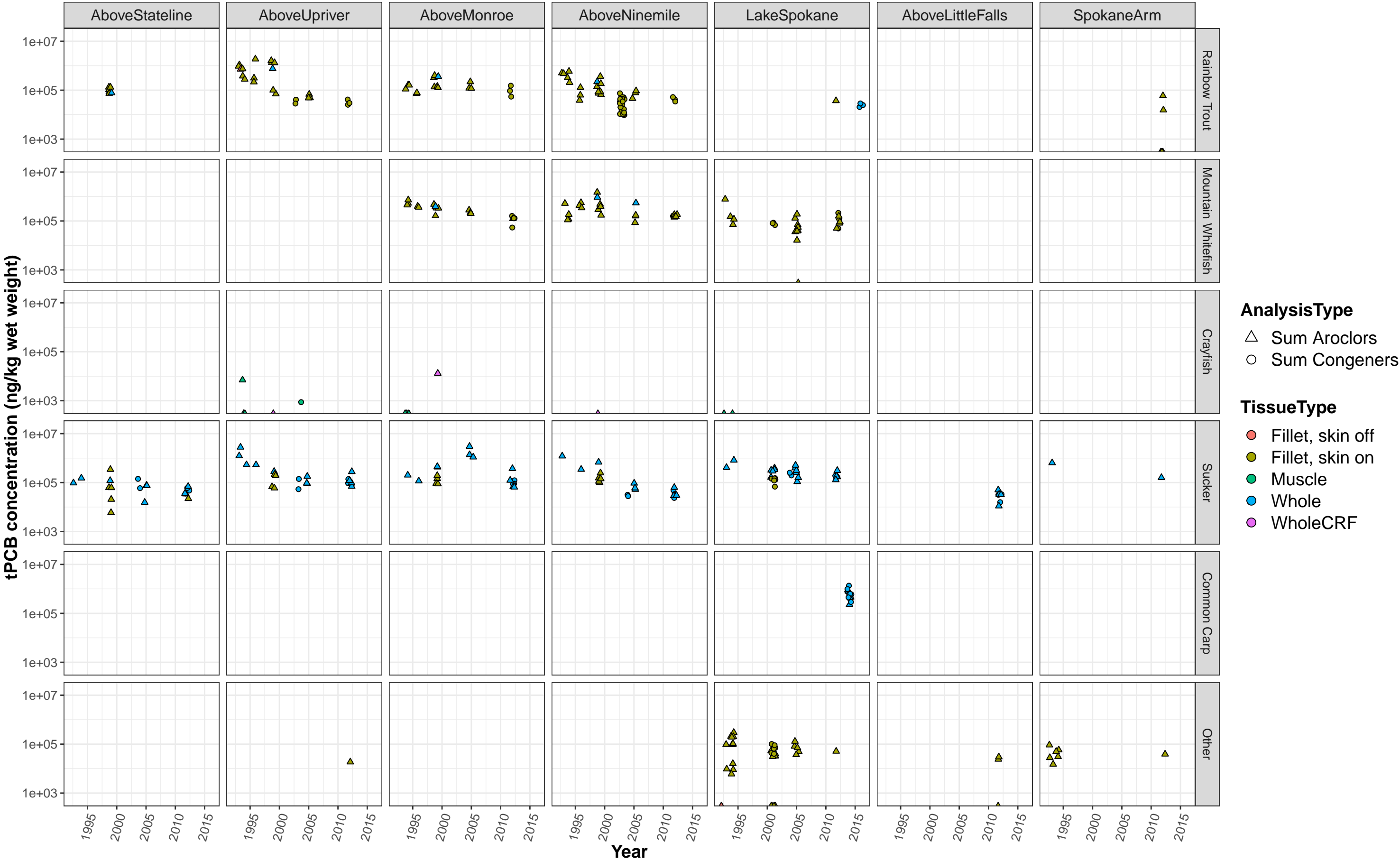


Figure 4B: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together.

Non-detects assigned half DL.

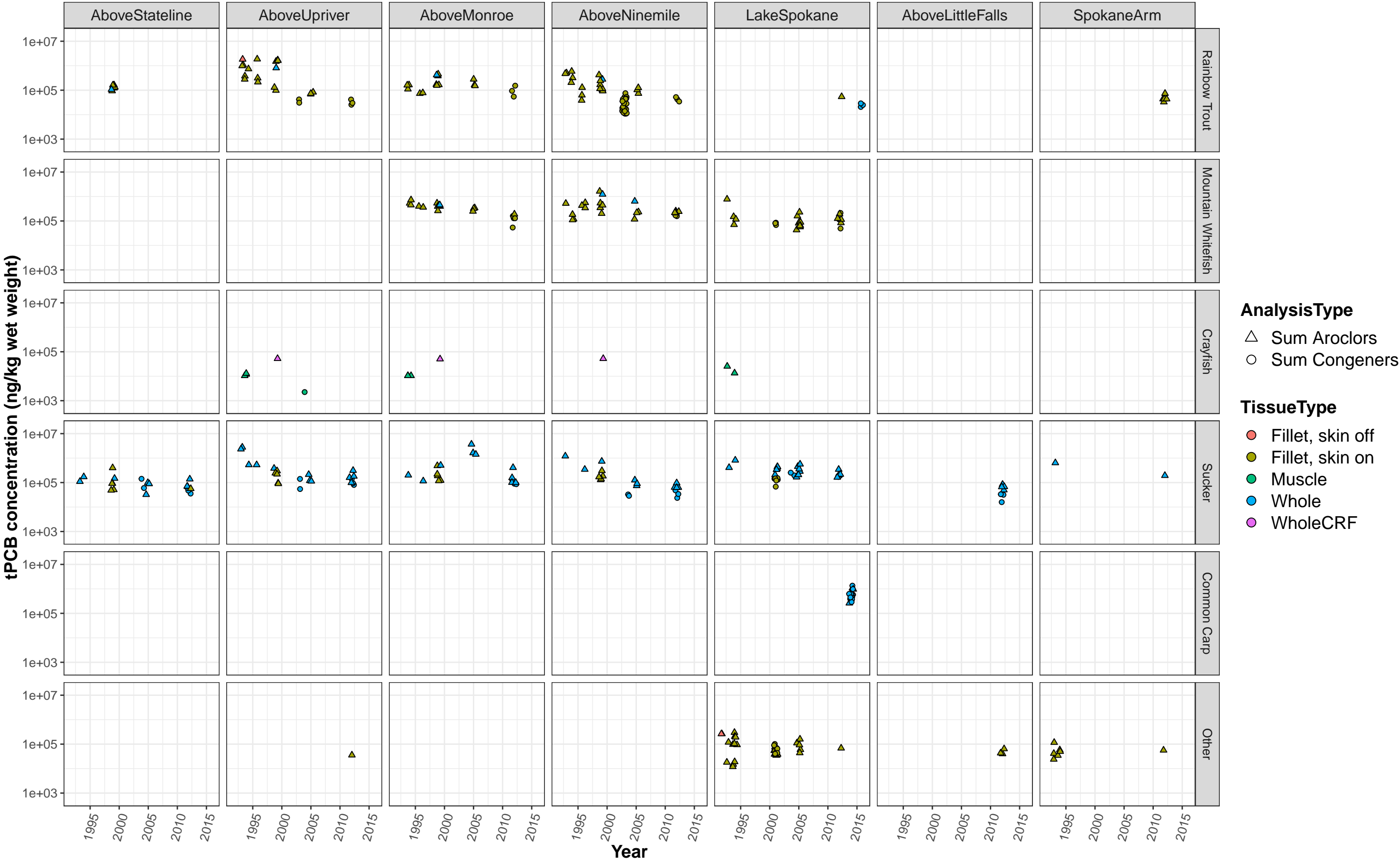


Figure 4C: Total PCB concentrations in fish from the Spokane River (ng/kg wet weight) as a function of year. Subset by the main species and river stretch, other species are grouped together.

Non-detects assigned full DL.

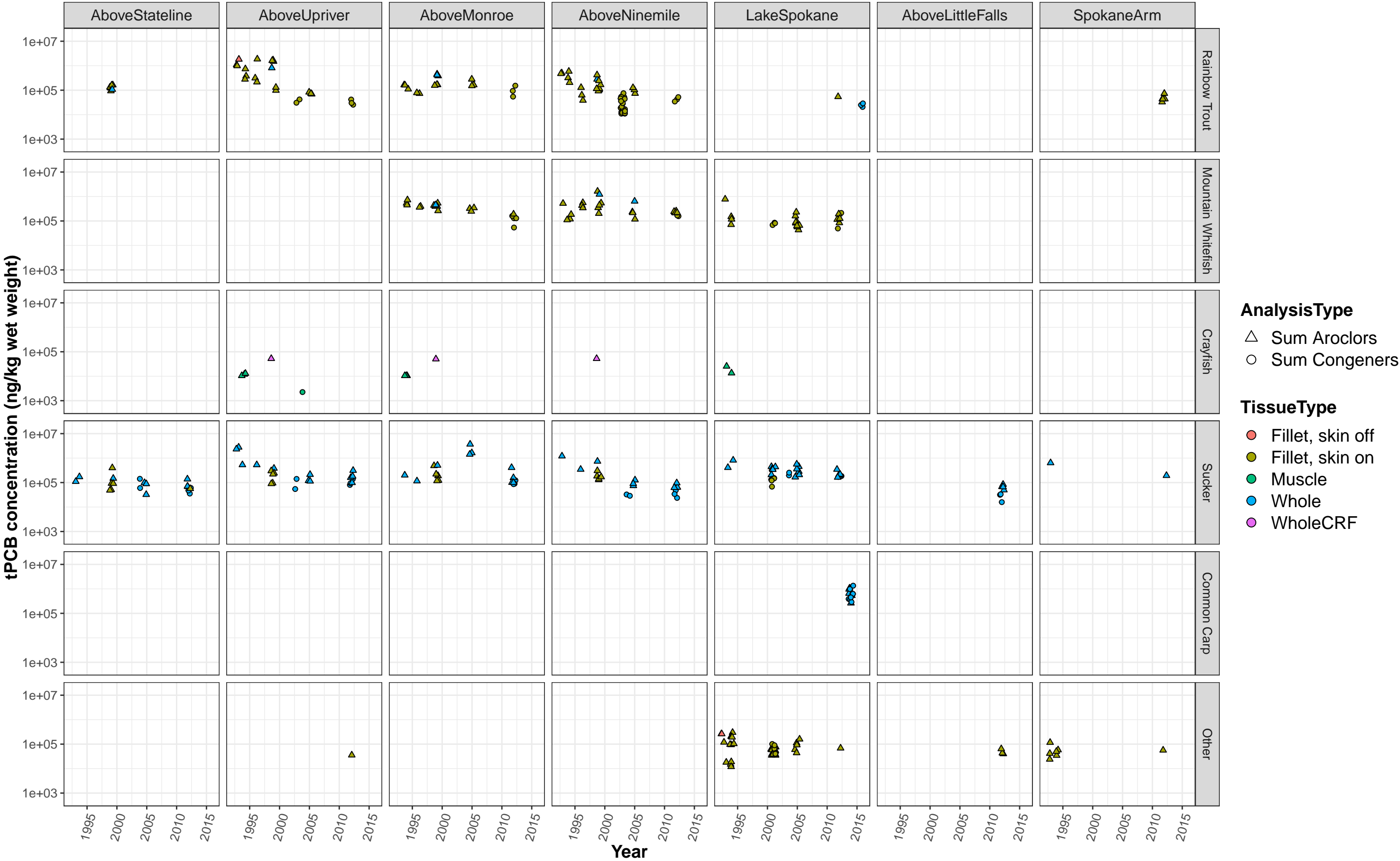


Figure 4D: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned zero.

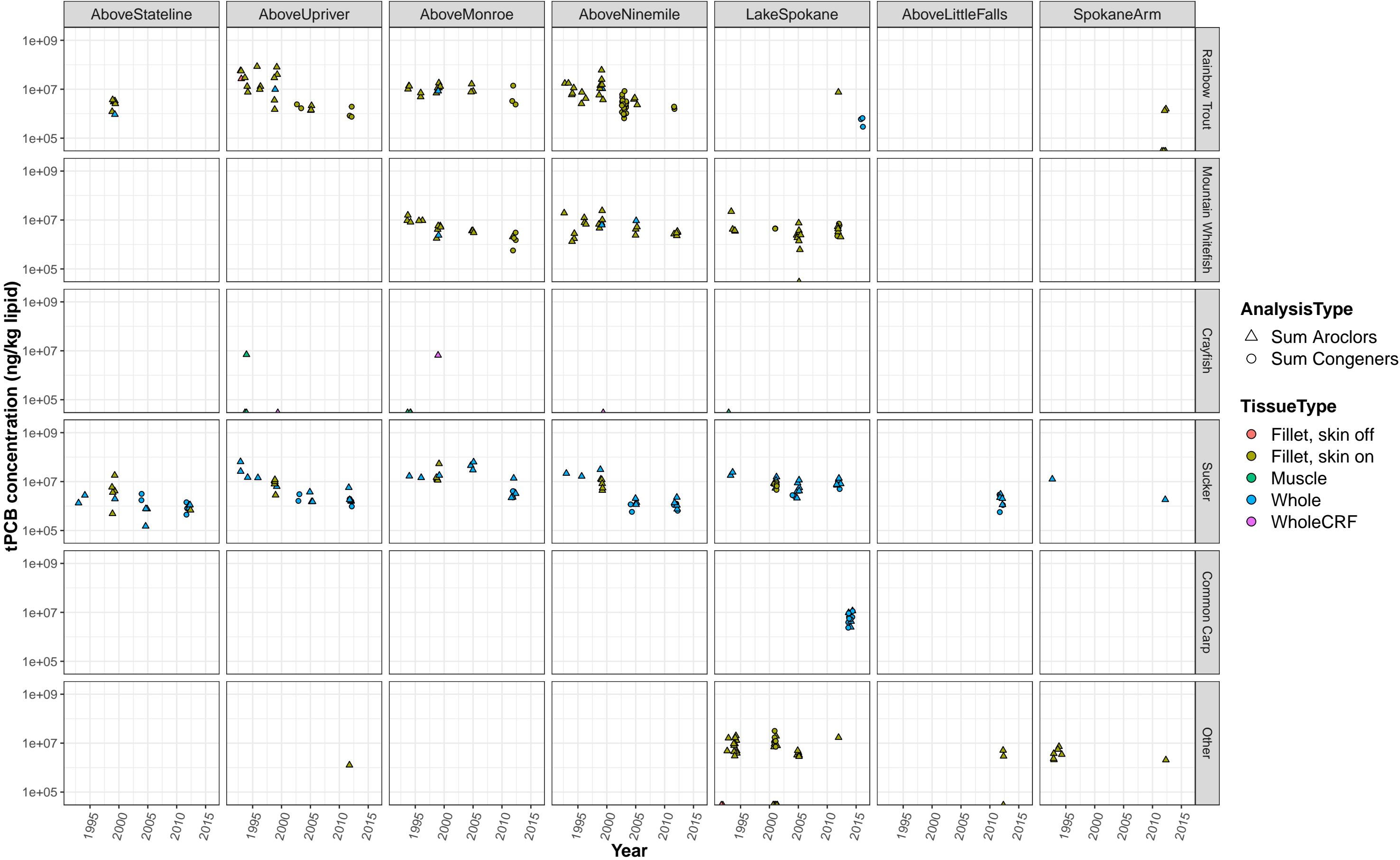


Figure 4E: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together.

Non-detects assigned half DL.

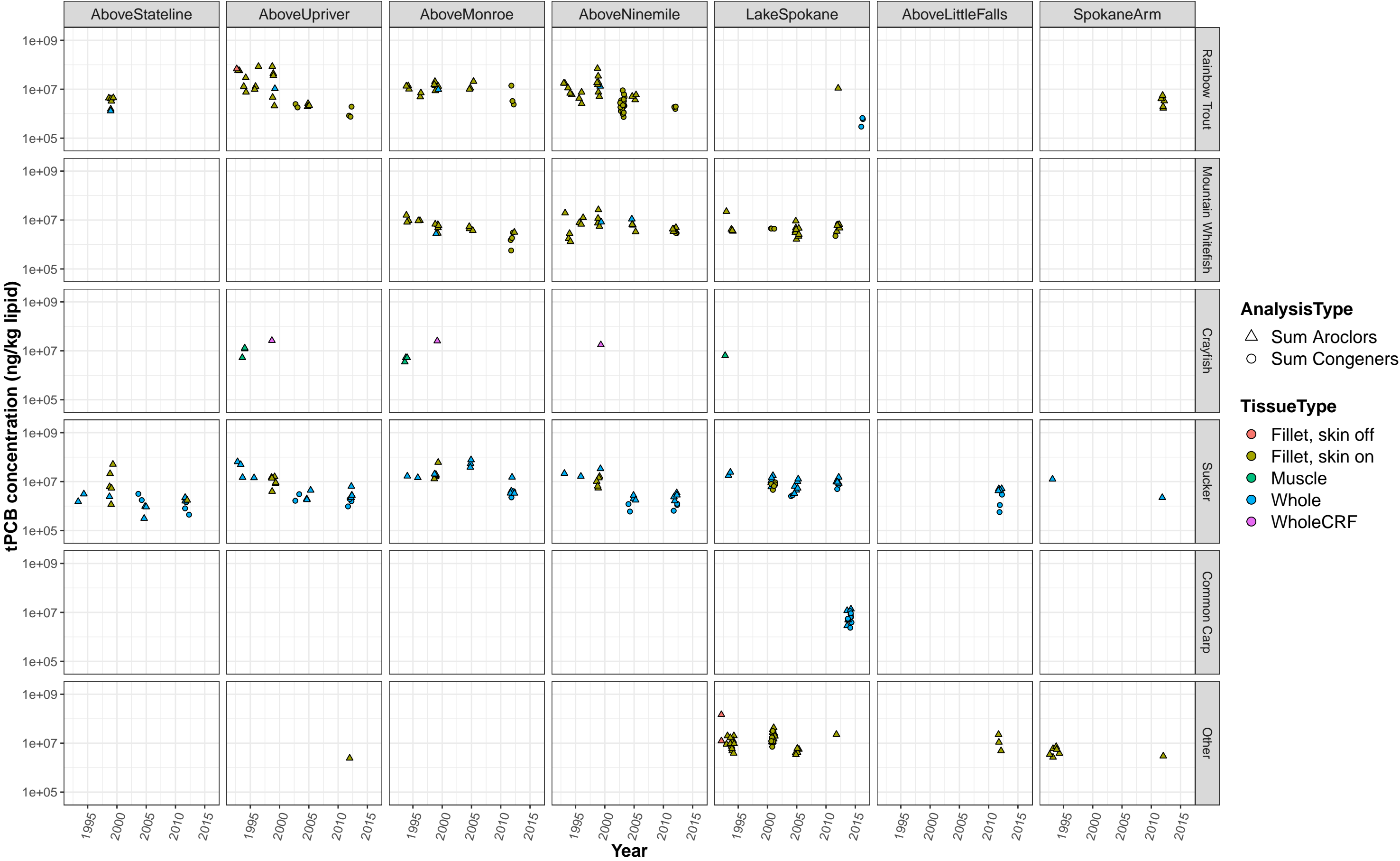


Figure 4F: Total PCB concentrations in fish from the Spokane River (ng/kg lipid) as a function of year. Subset by the main species and river stretch, other species are grouped together. Non-detects assigned full DL.

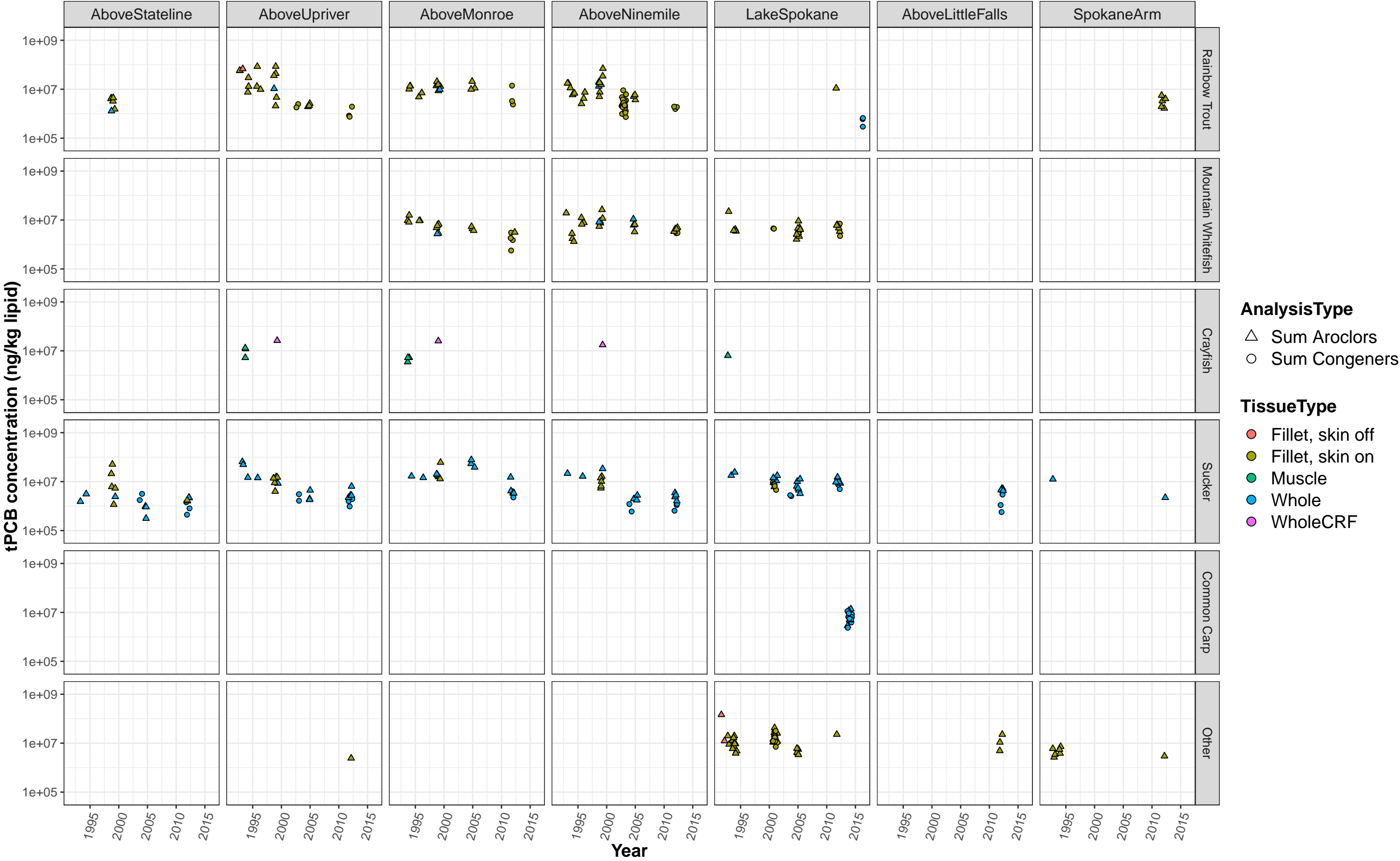


Figure 5A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by year and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned zero.

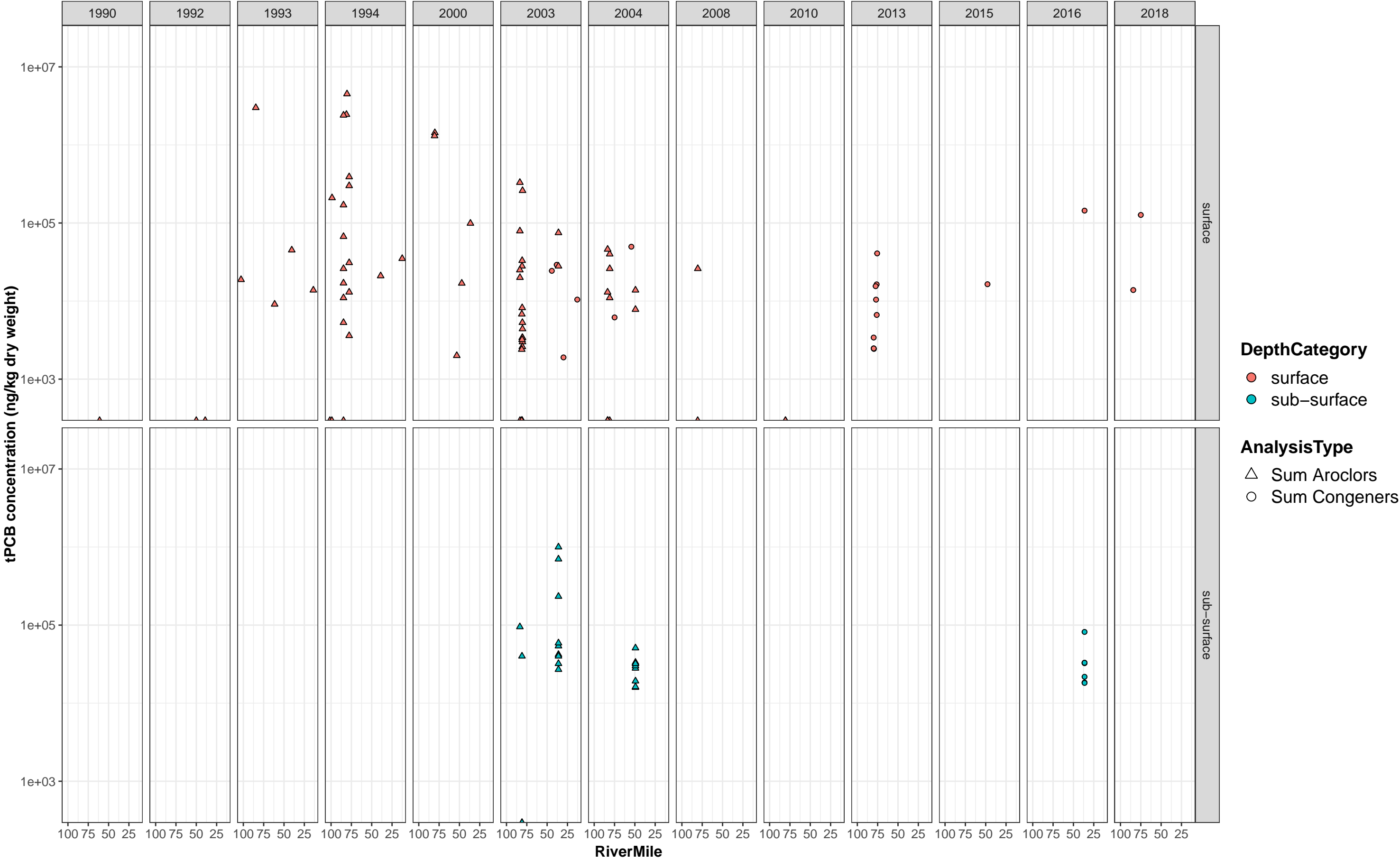


Figure 5B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

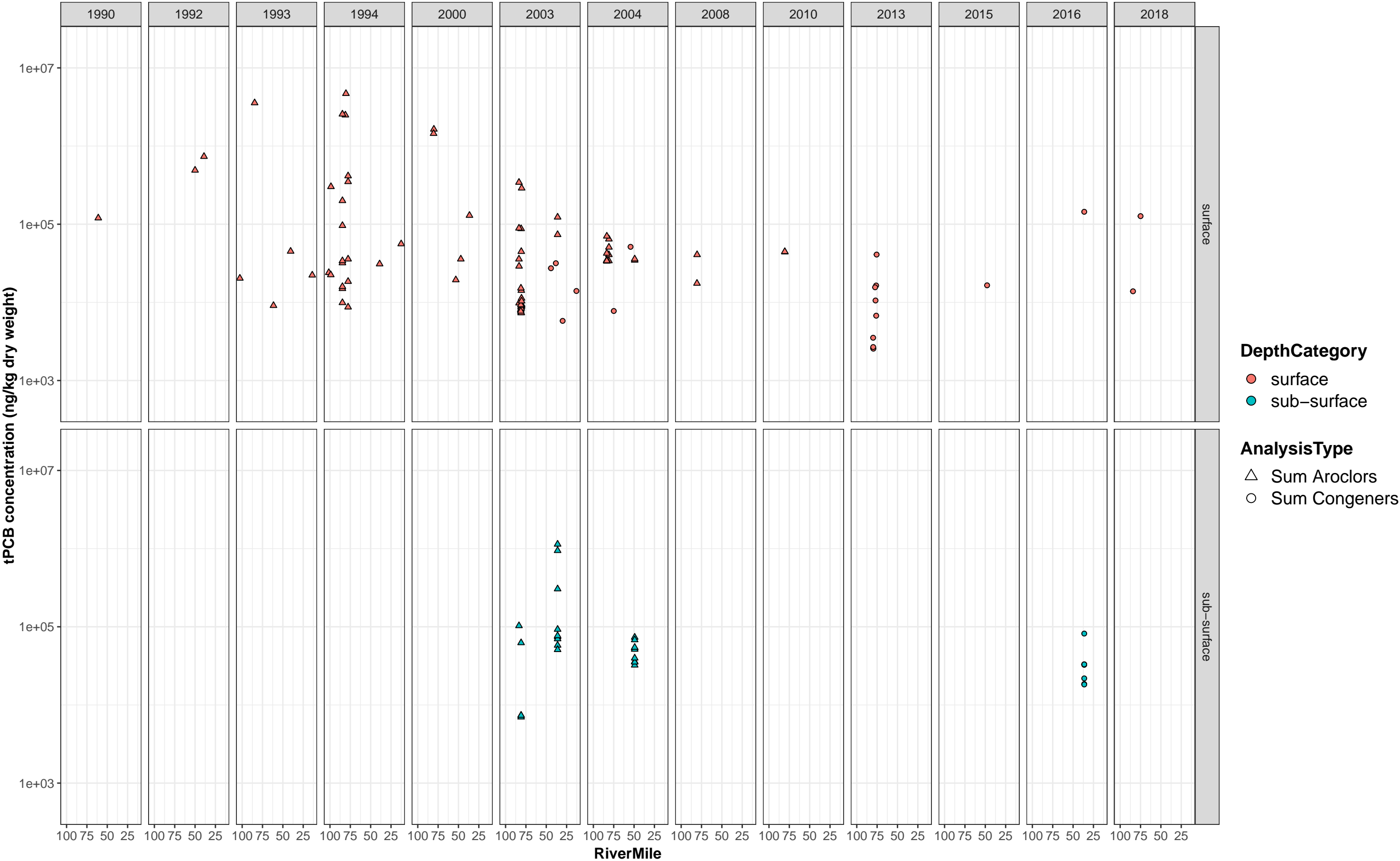


Figure 5C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by year and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

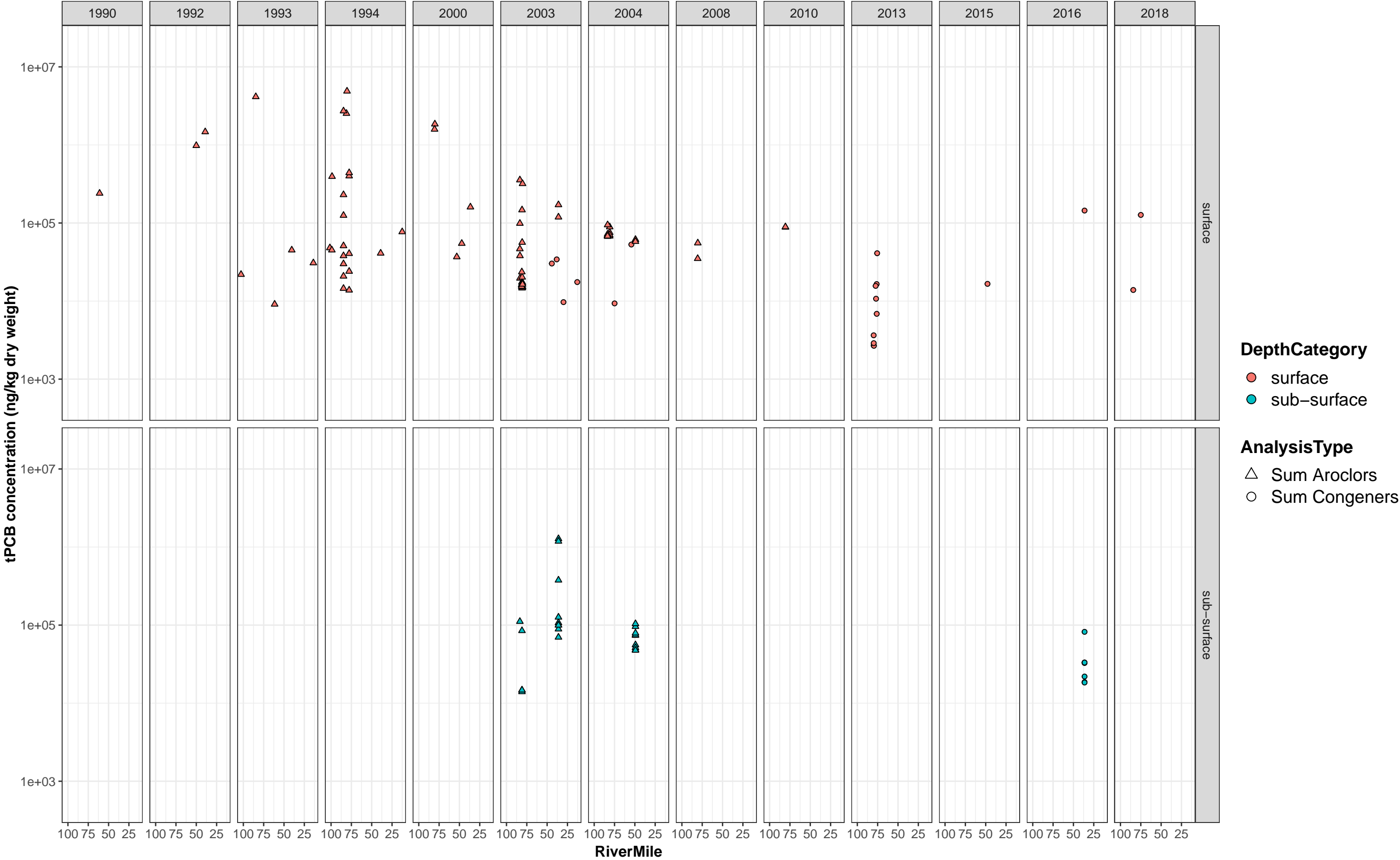


Figure 5D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by year and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned zero.

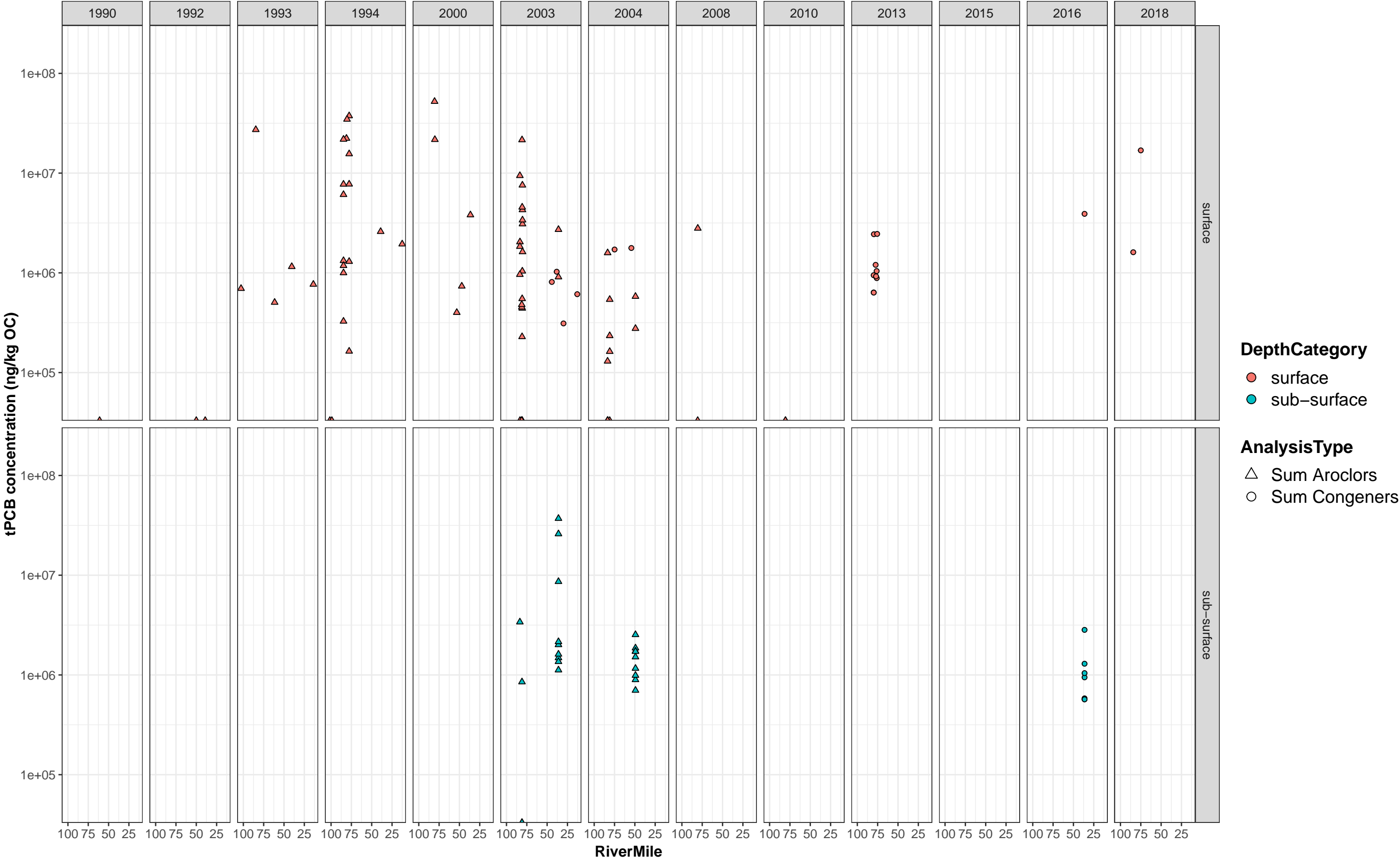


Figure 5E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by year and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned half DL.

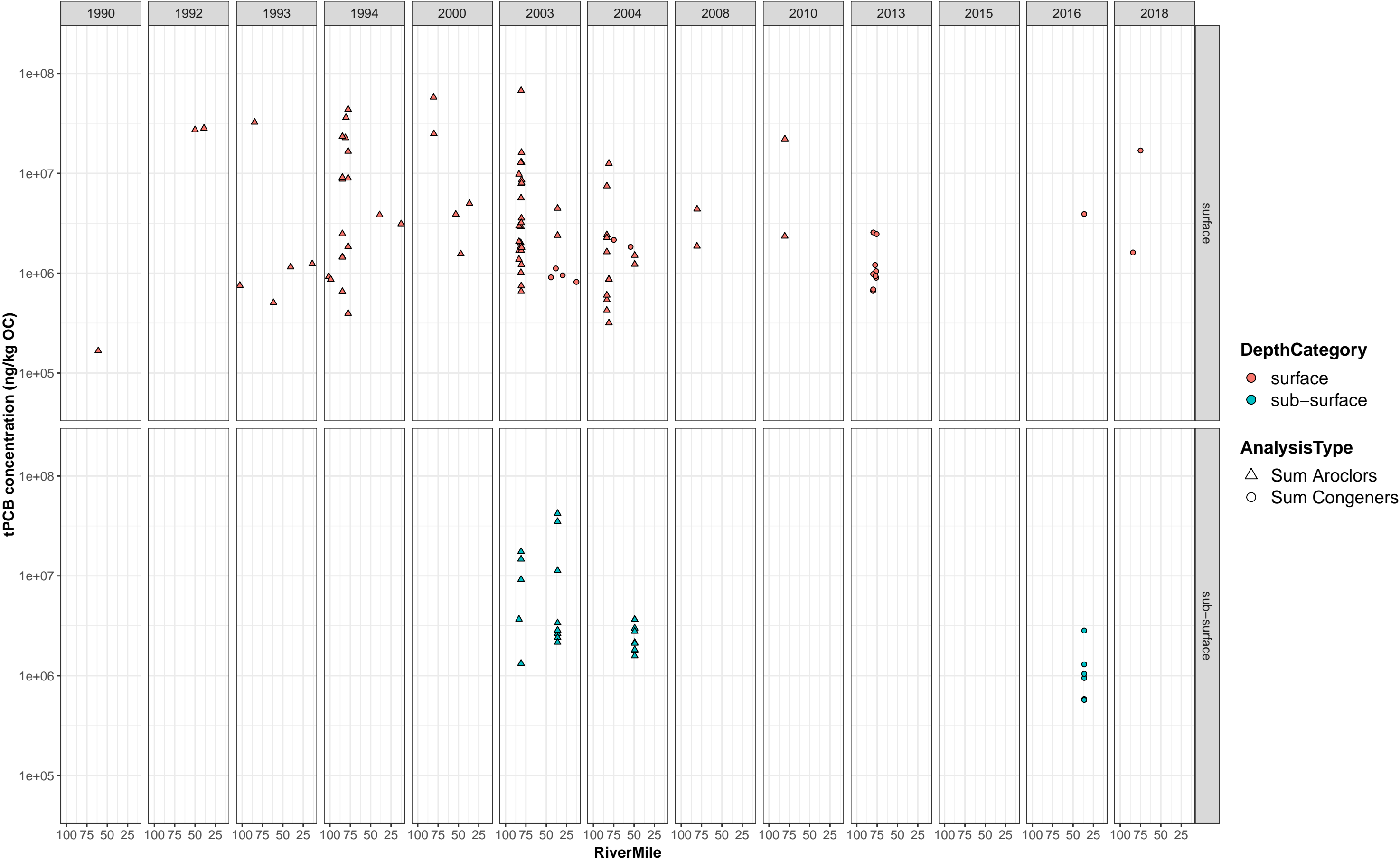


Figure 5F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by year and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned full DL.

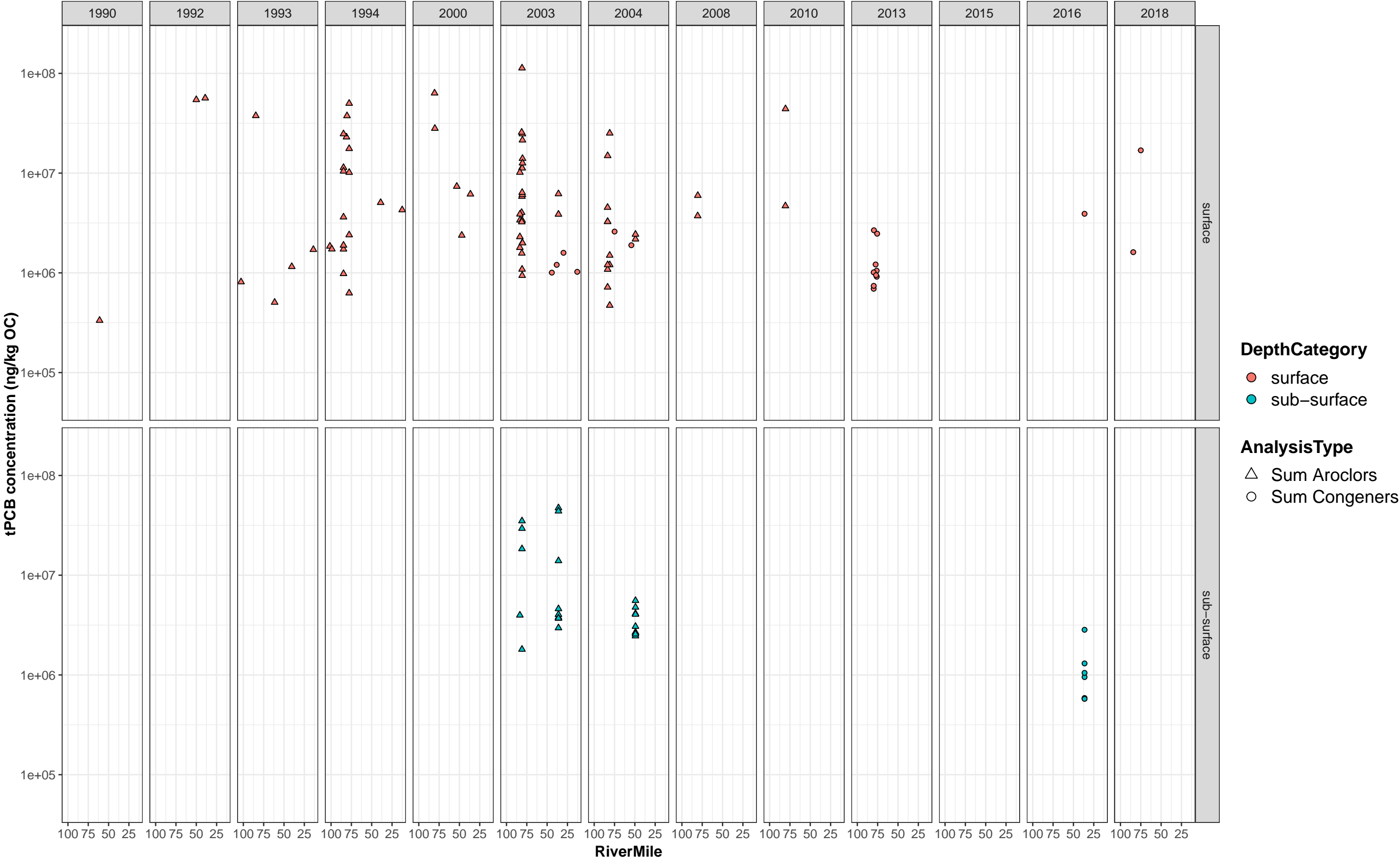


Figure 6A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

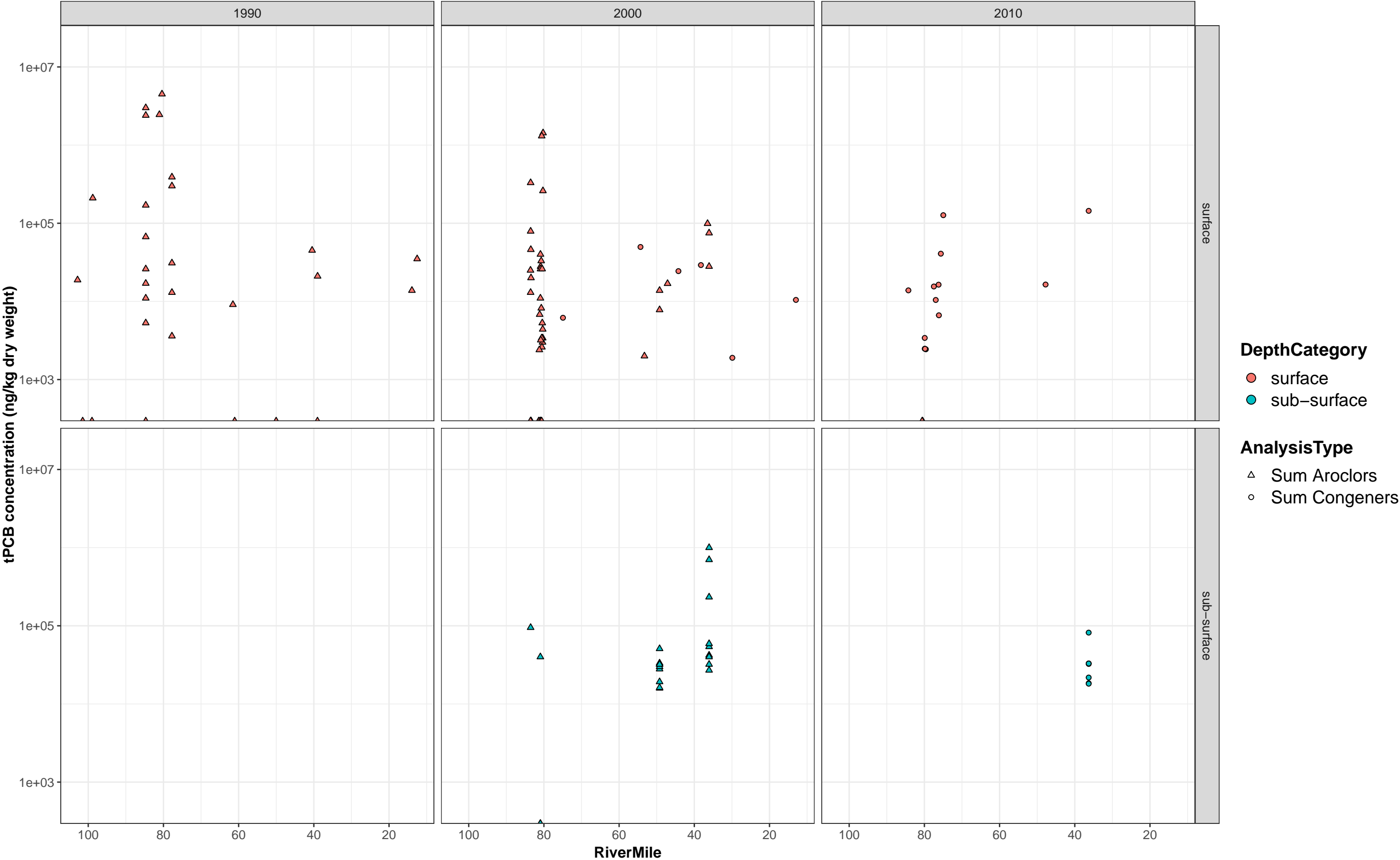


Figure 6B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

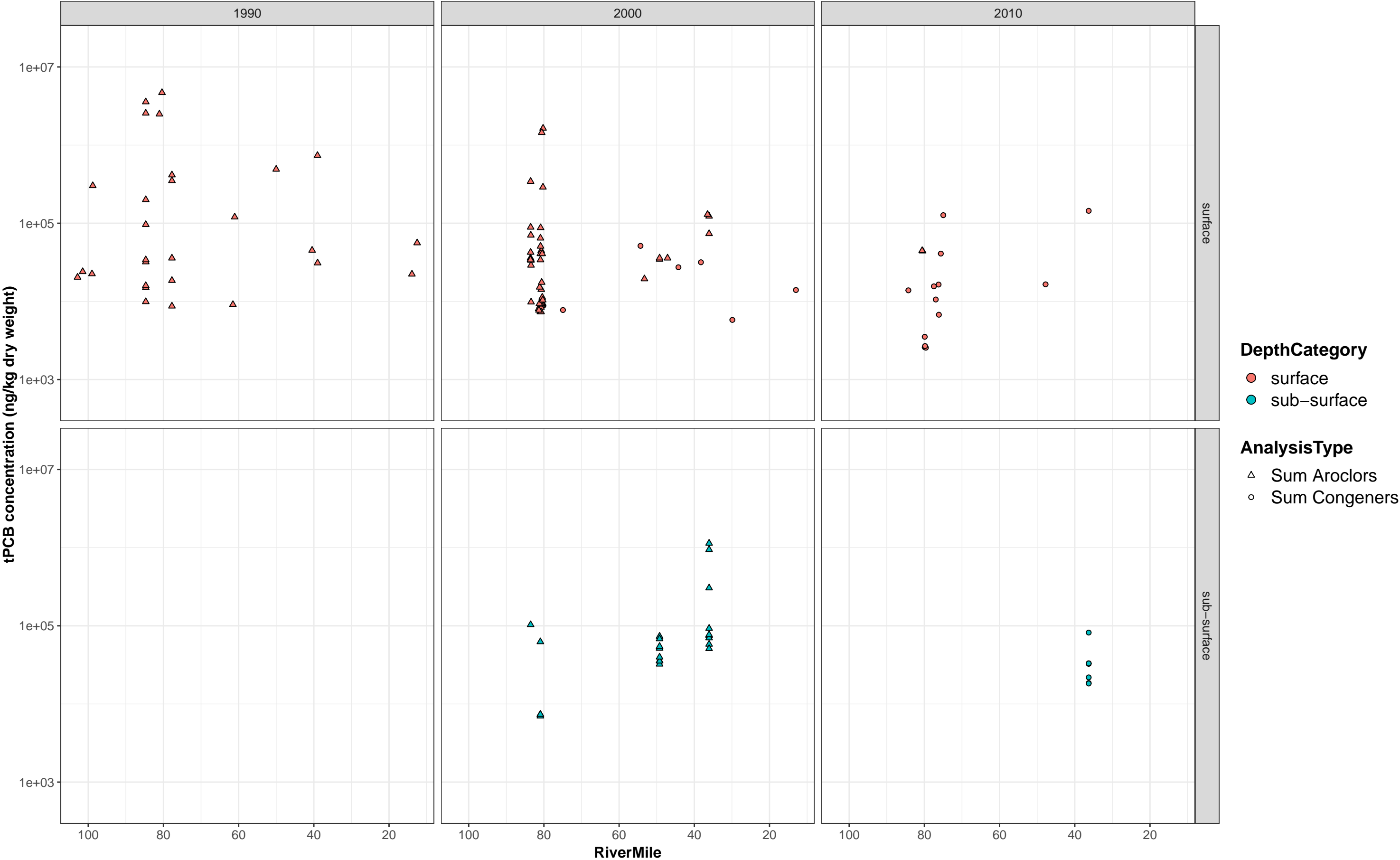


Figure 6C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

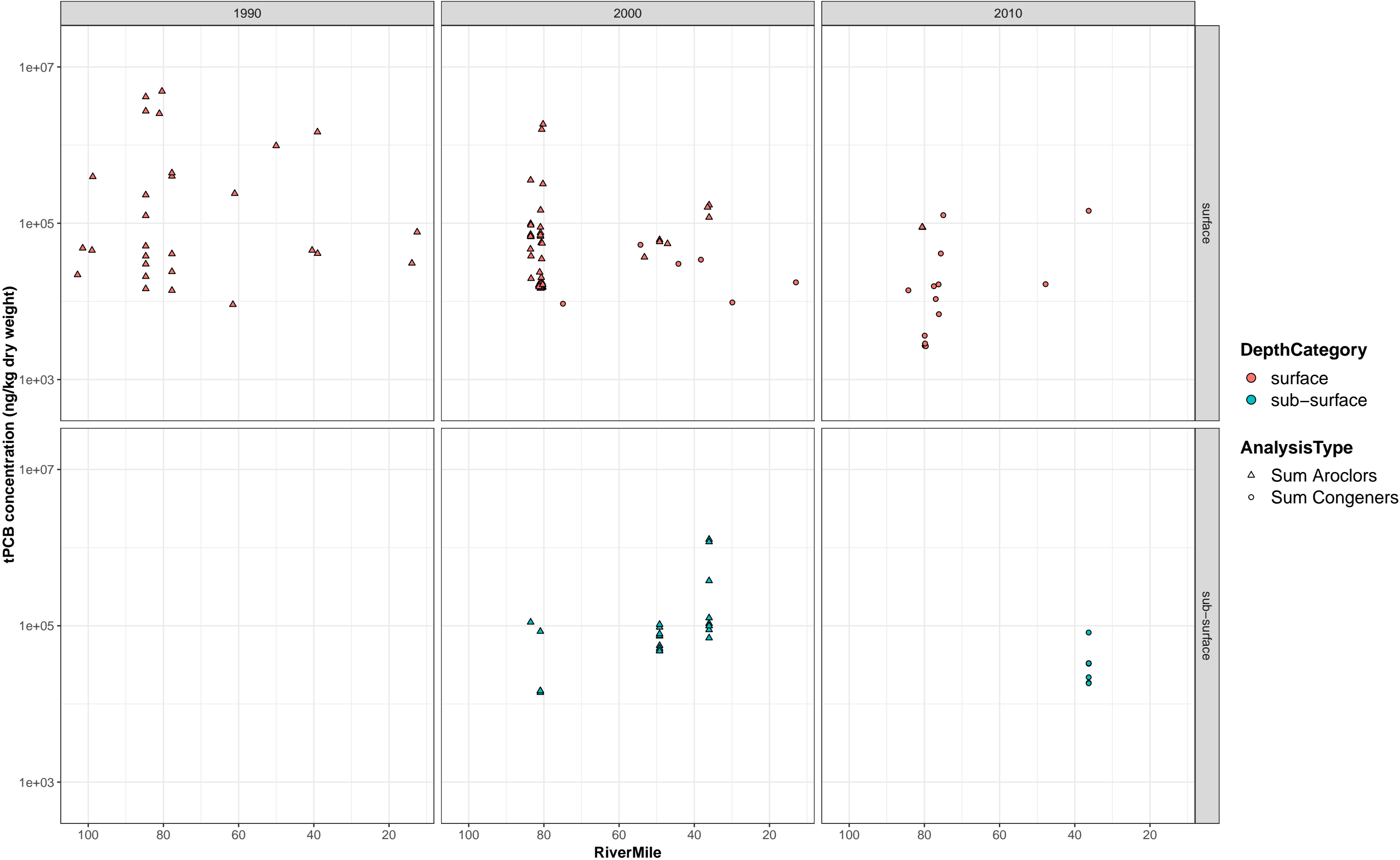


Figure 6D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

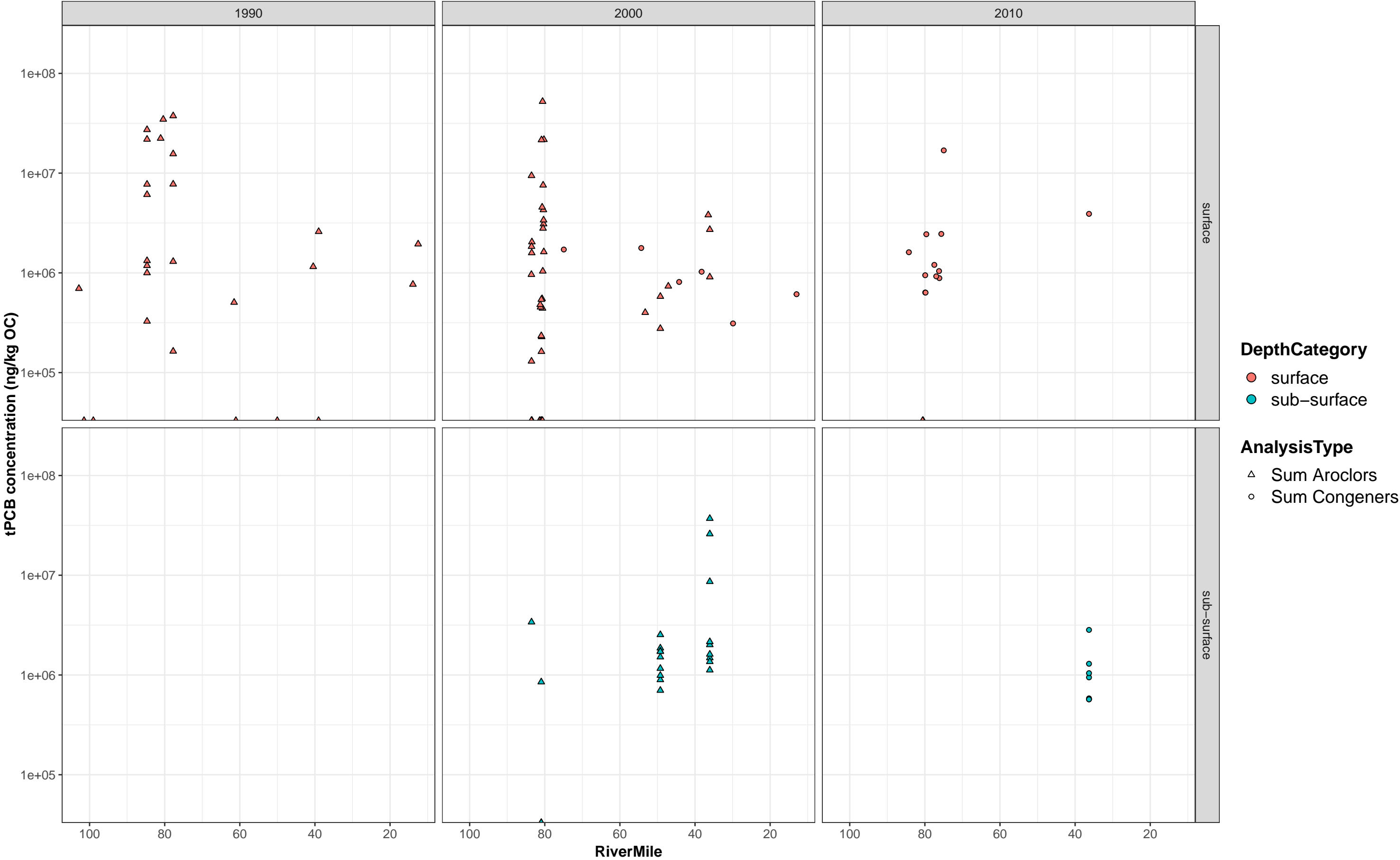


Figure 6E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by decade and depth category - surface and sub-surface.

Individual congener/Aroclor non-detects assigned half DL.

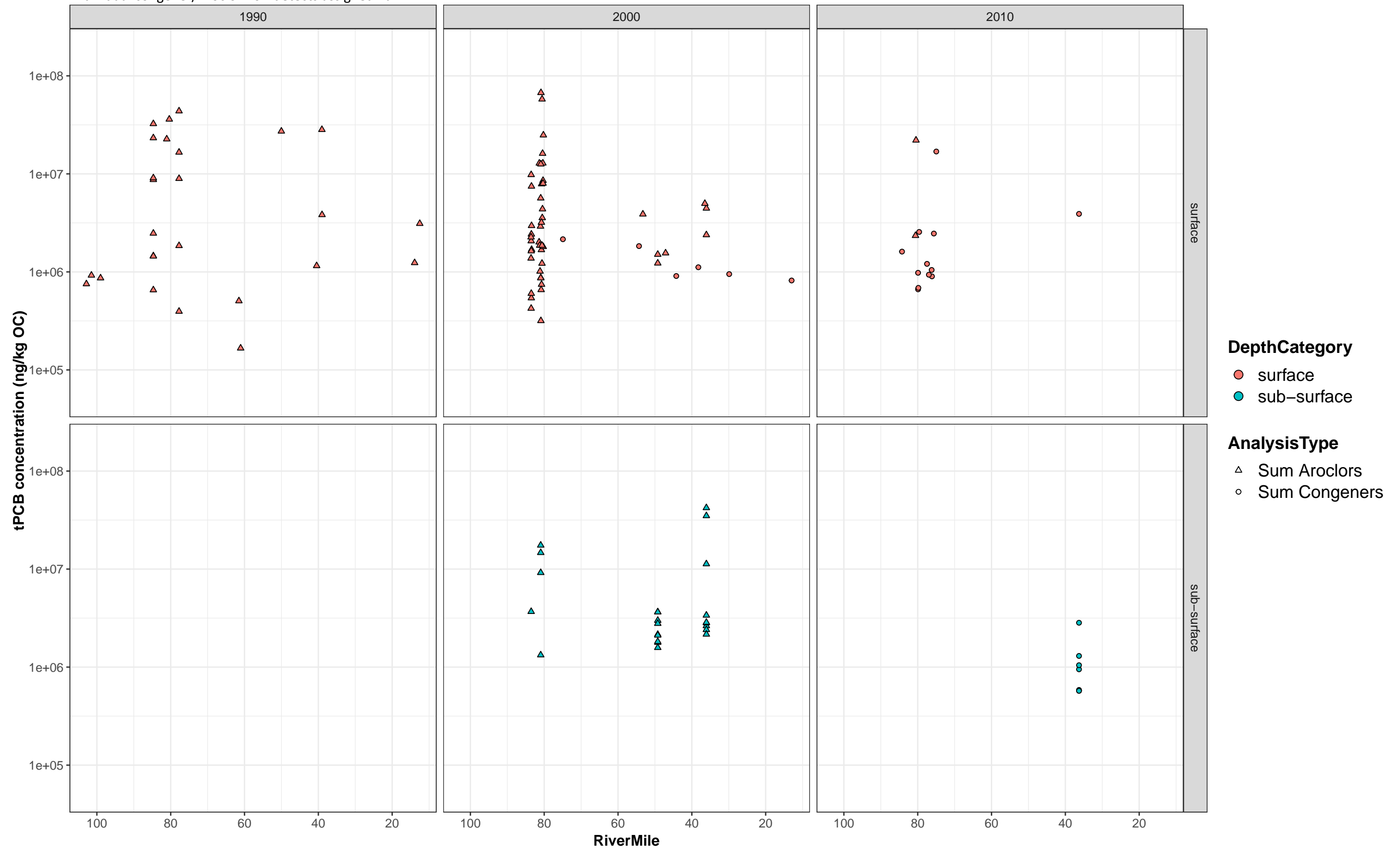


Figure 6F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river mile. Subset by decade and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

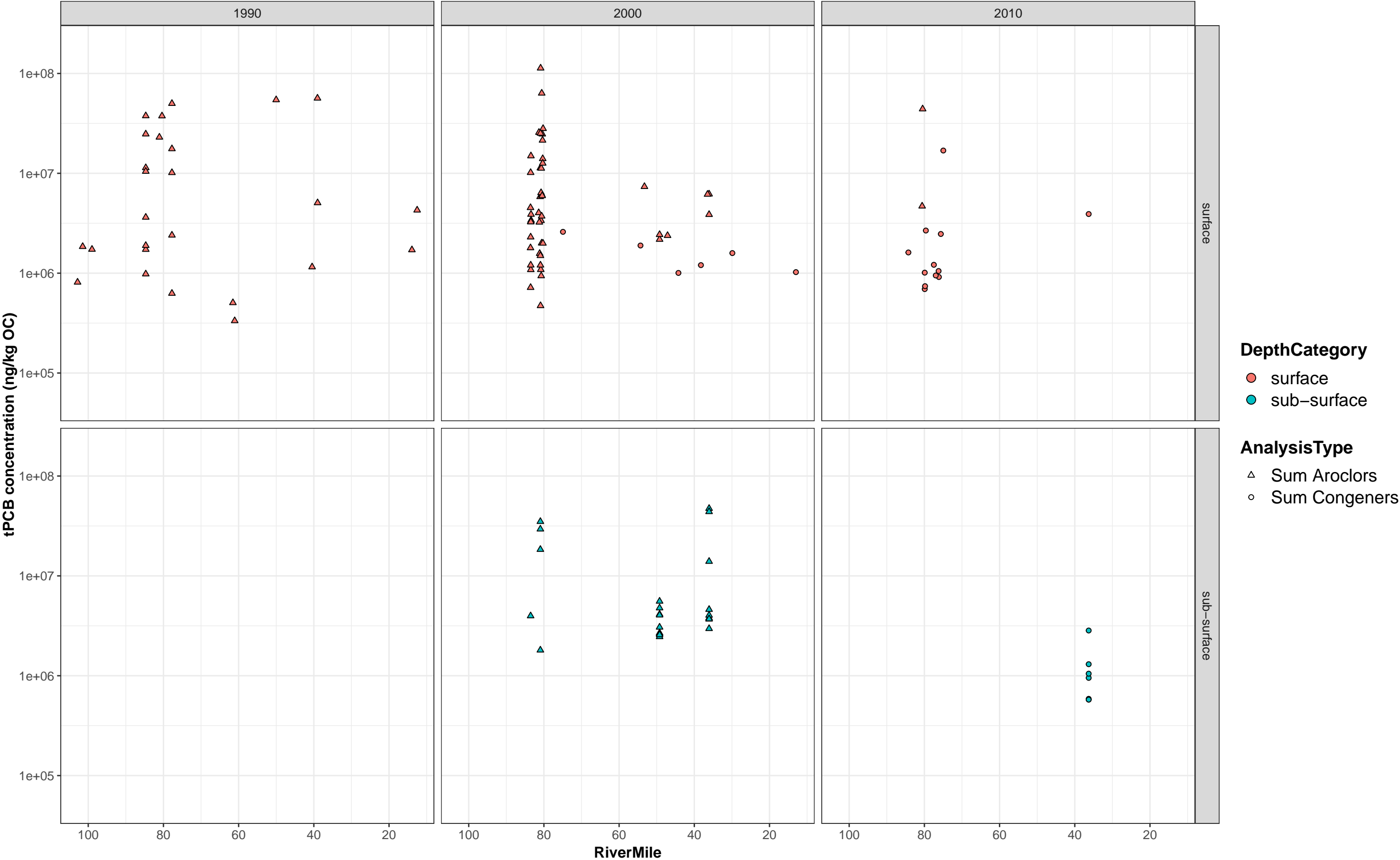


Figure 7A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned zero.

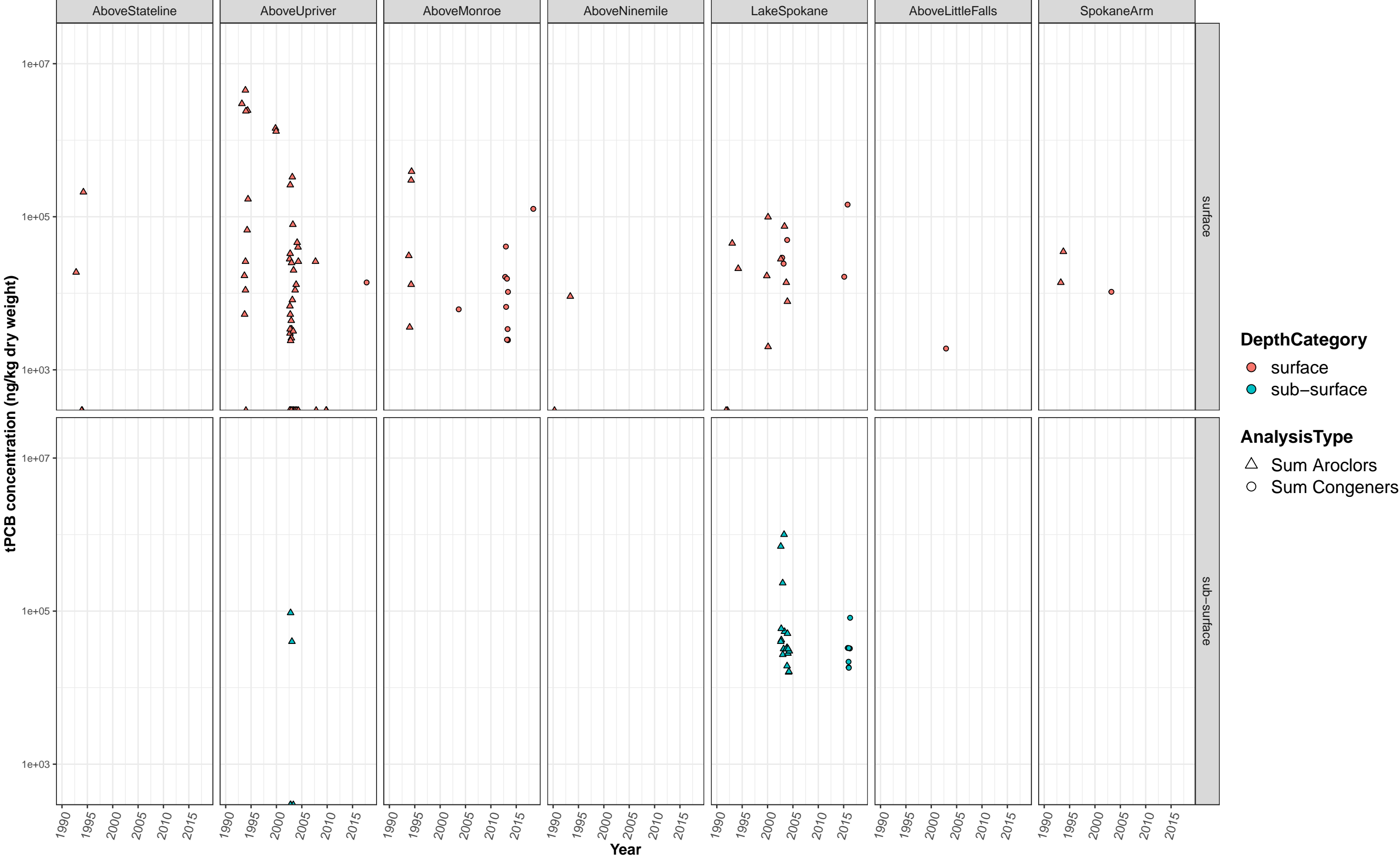


Figure 7B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned half DL.

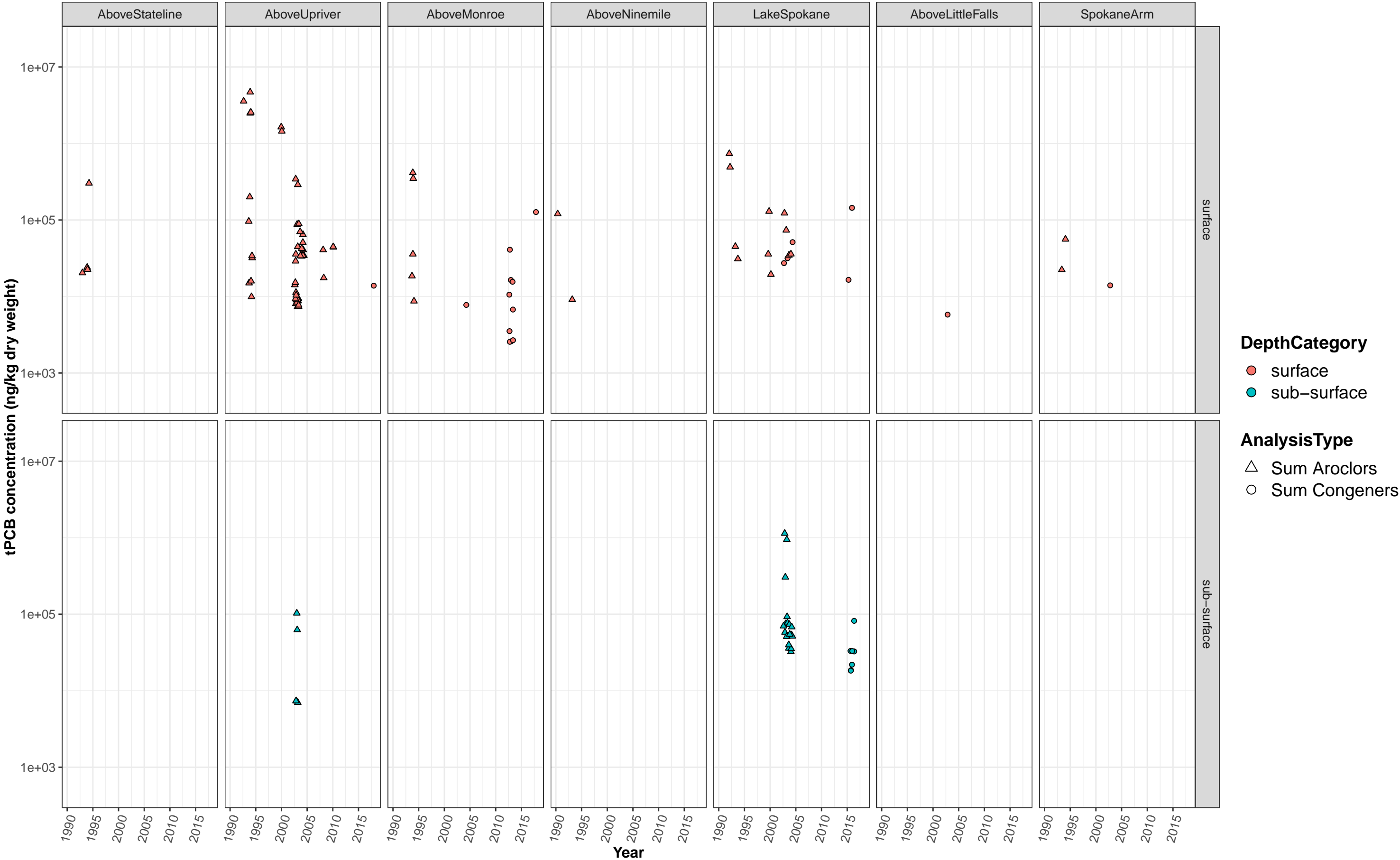


Figure 7C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

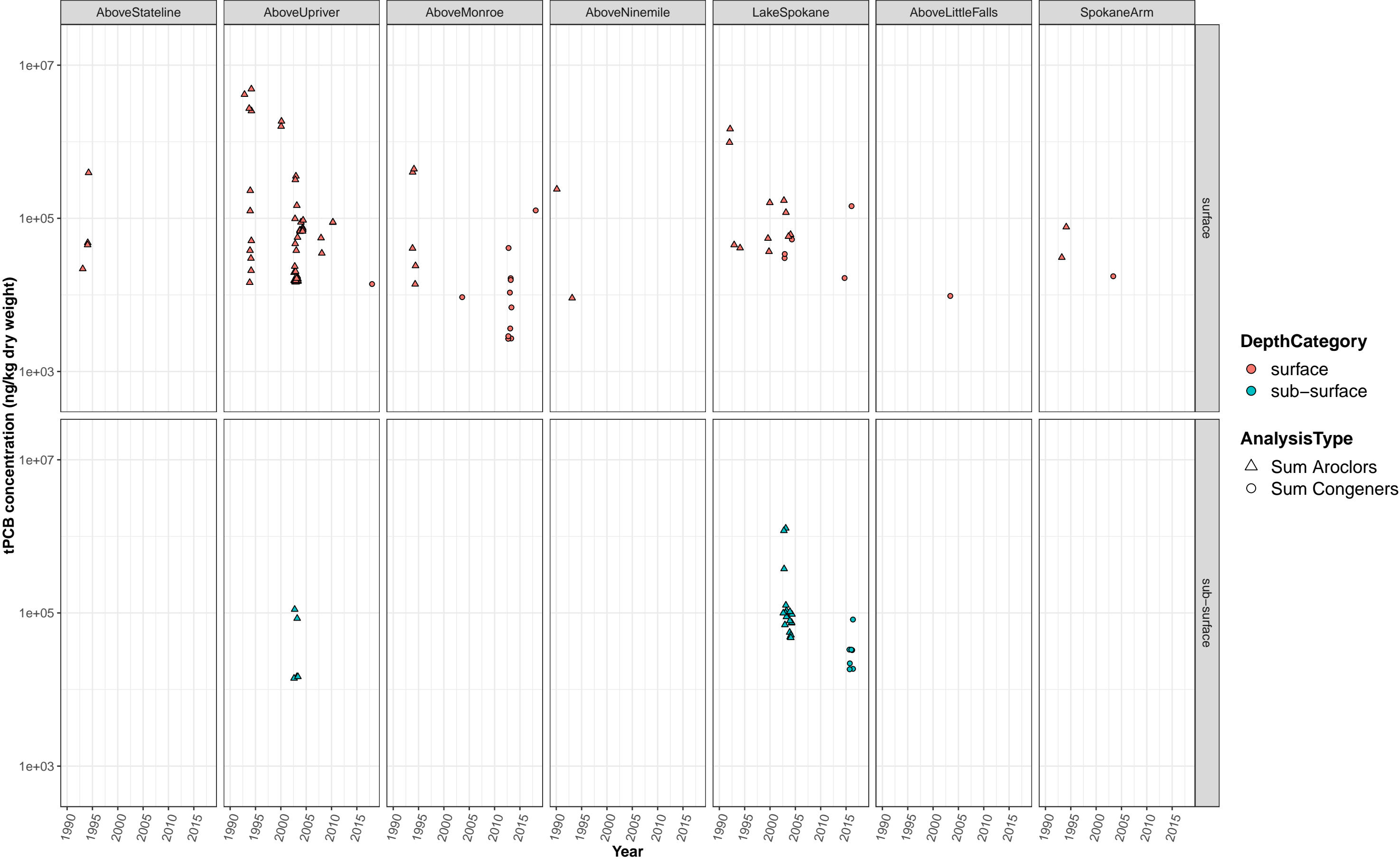


Figure 7D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned zero.

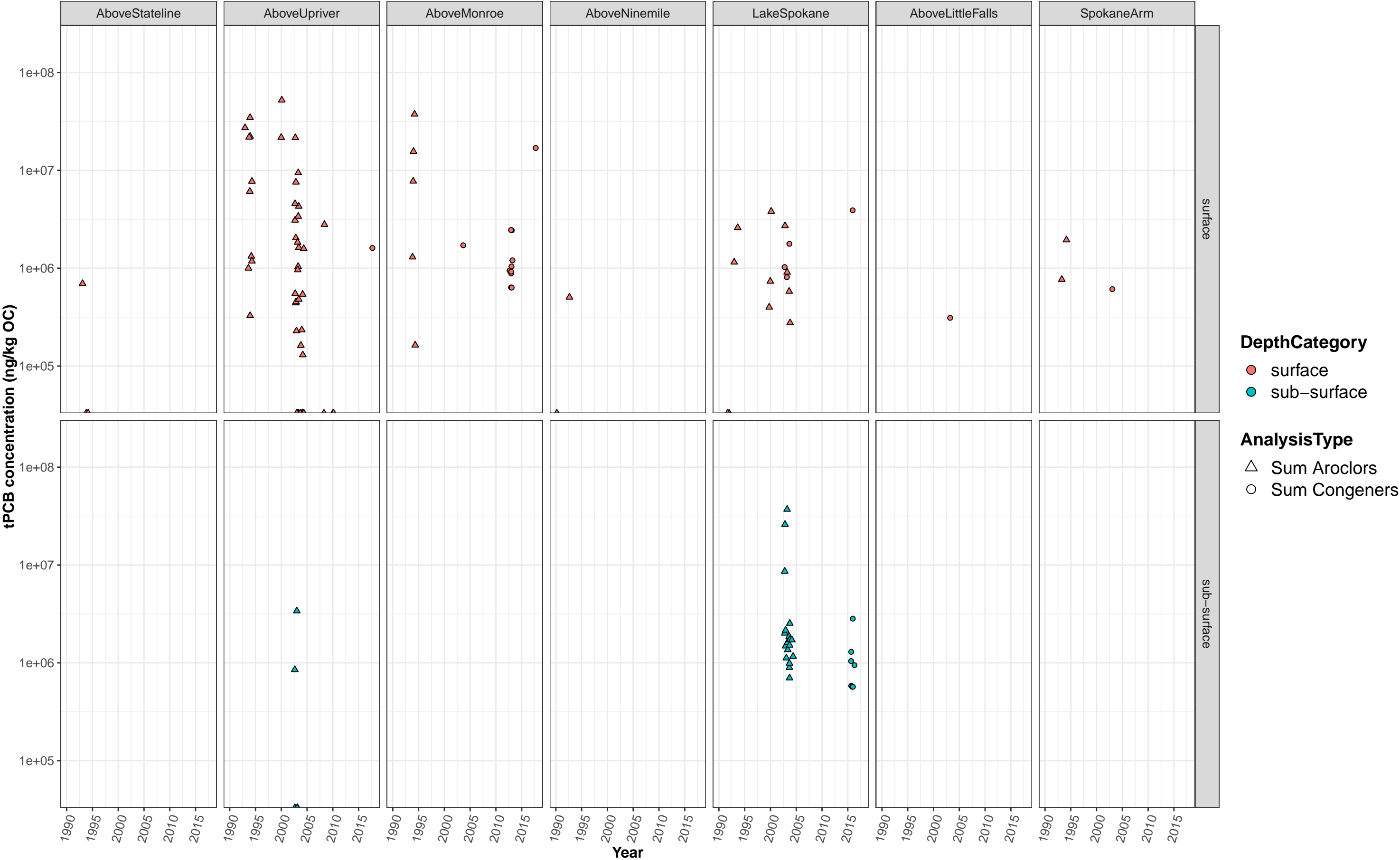


Figure 7E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface.
Individual congener/Aroclor non-detects assigned half DL.

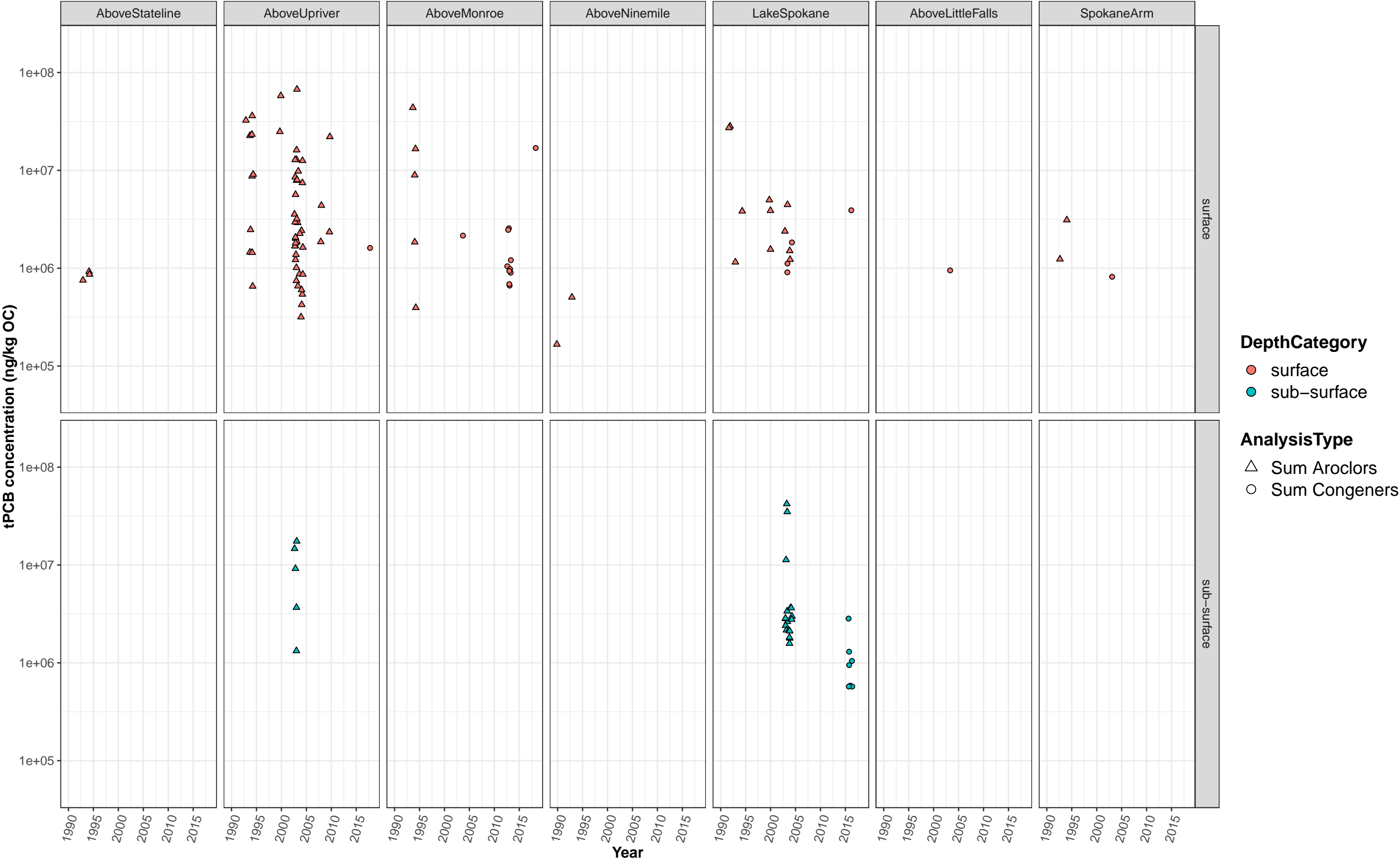


Figure 7F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch and depth category - surface and sub-surface. Individual congener/Aroclor non-detects assigned full DL.

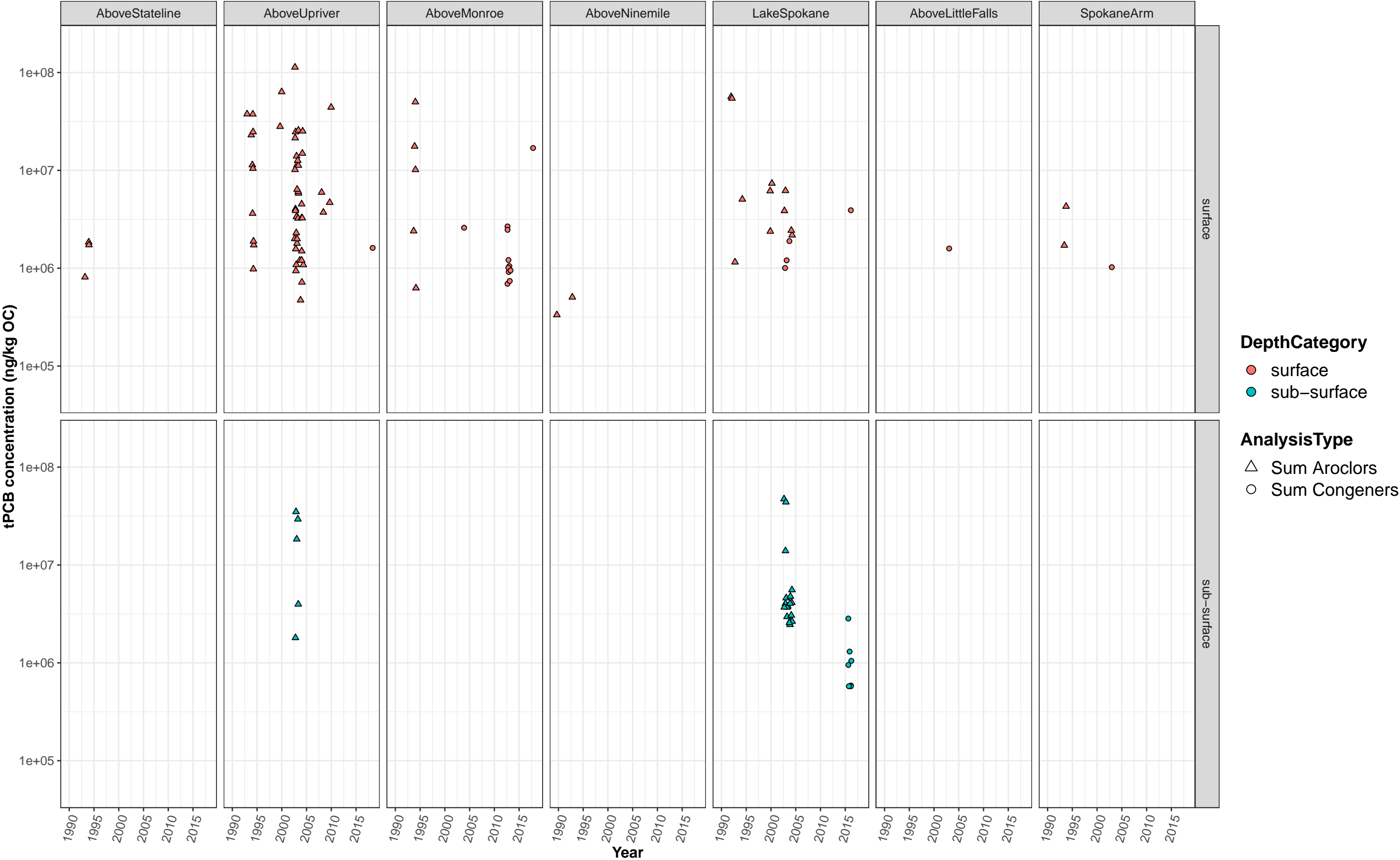


Figure 8A: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned zero.

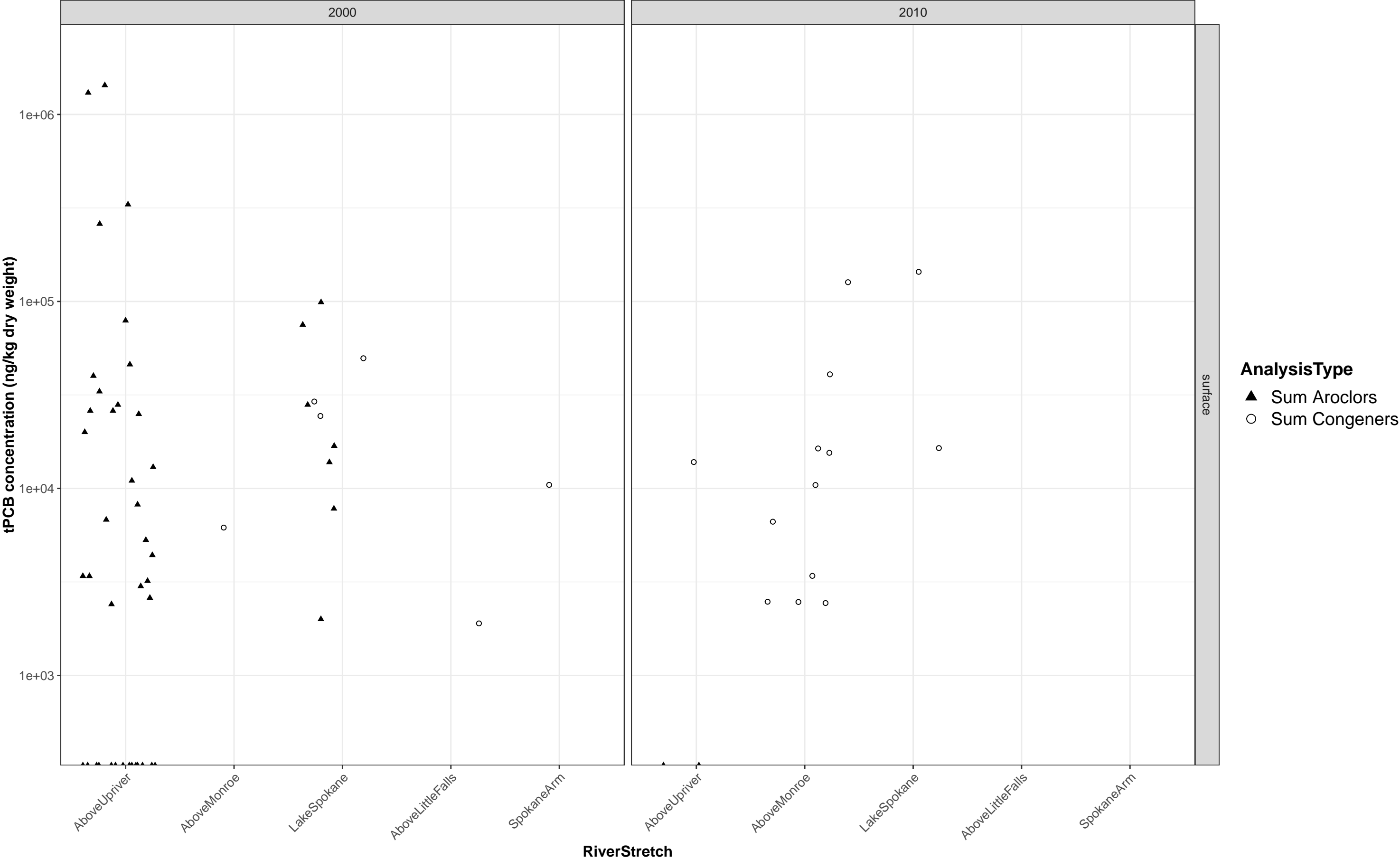


Figure 8B: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned half DL.

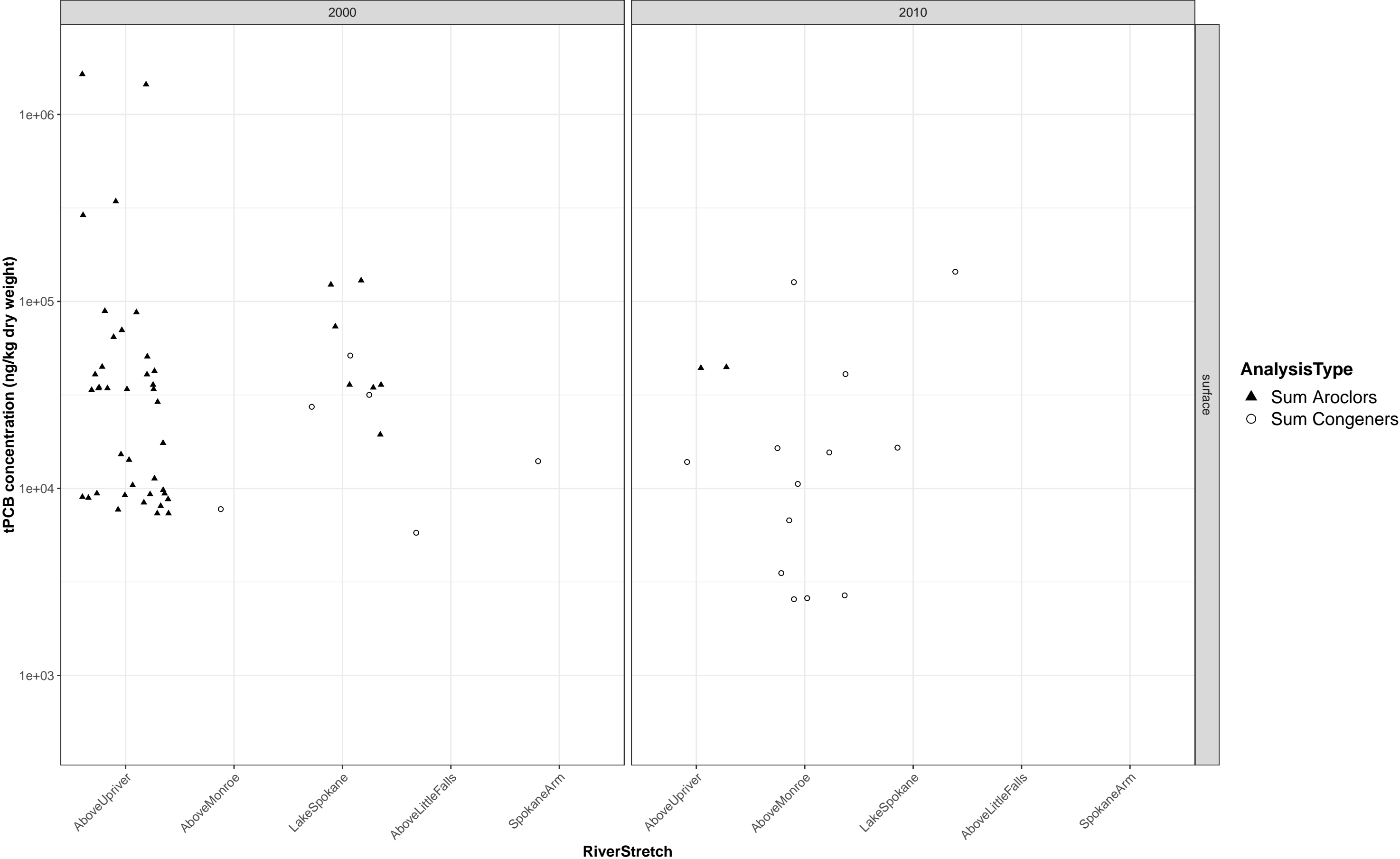


Figure 8C: Total PCB concentrations in sediment from the Spokane River (ng/kg dry weight) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned full DL.

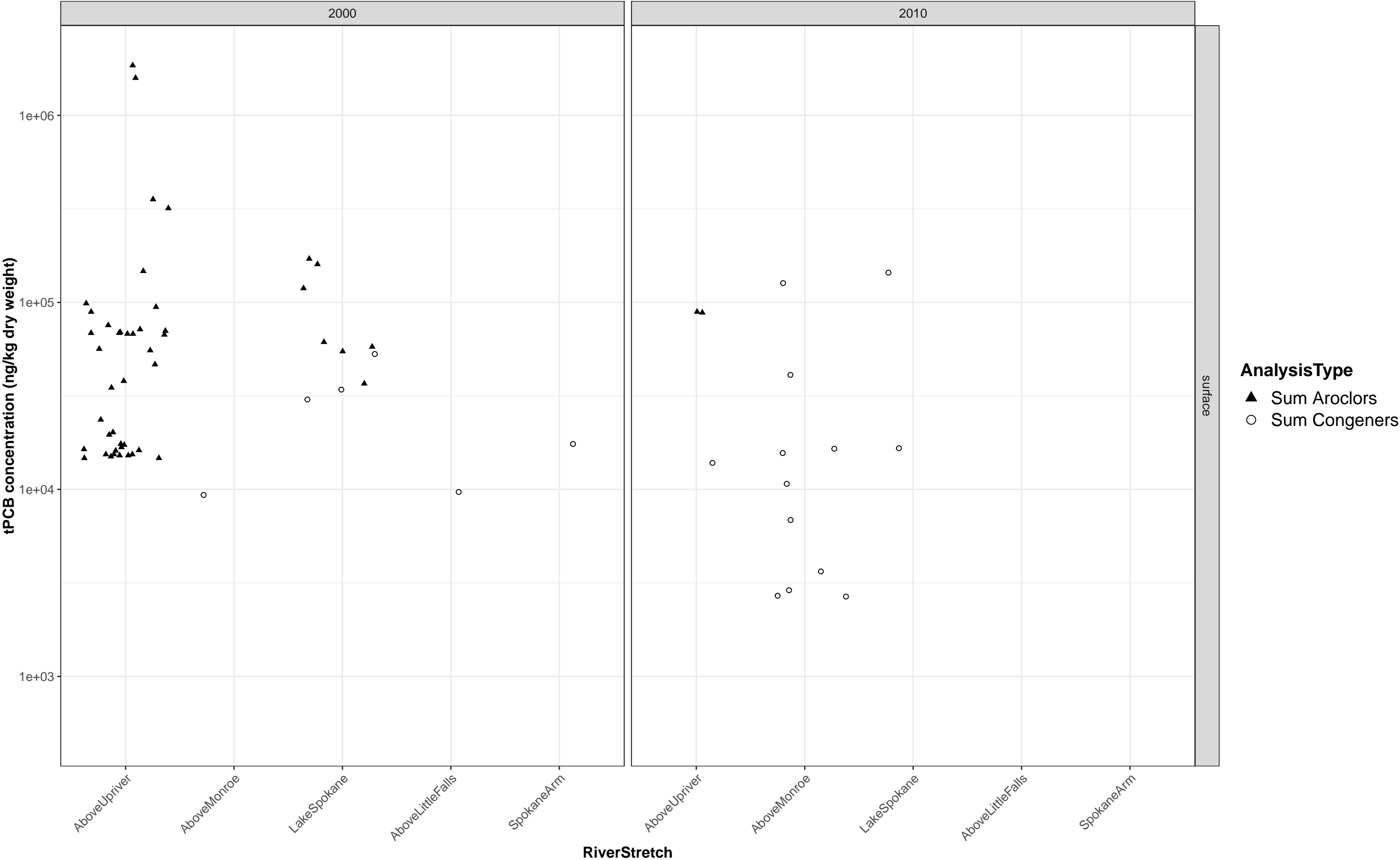


Figure 8D: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned zero.

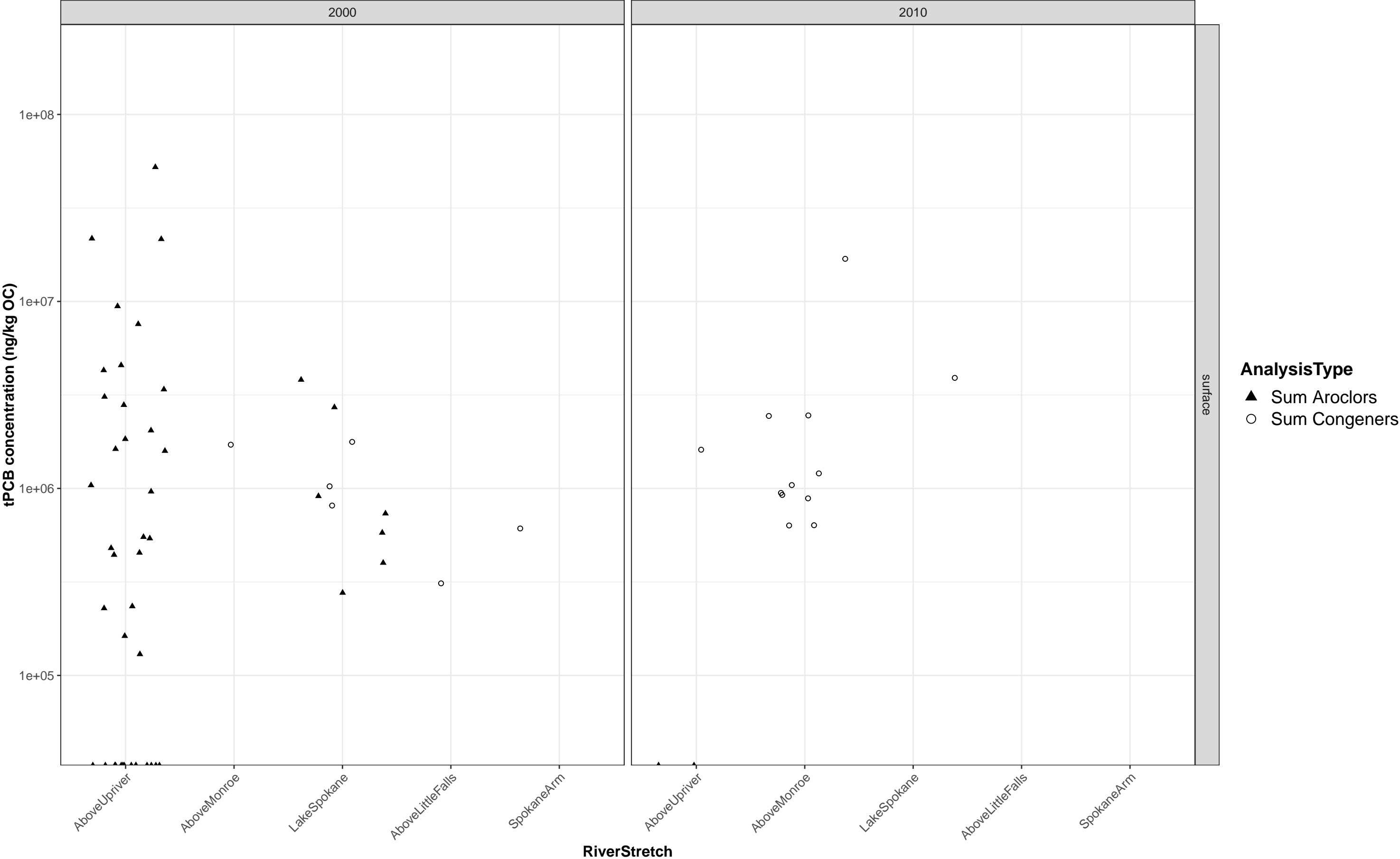


Figure 8E: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned half DL.

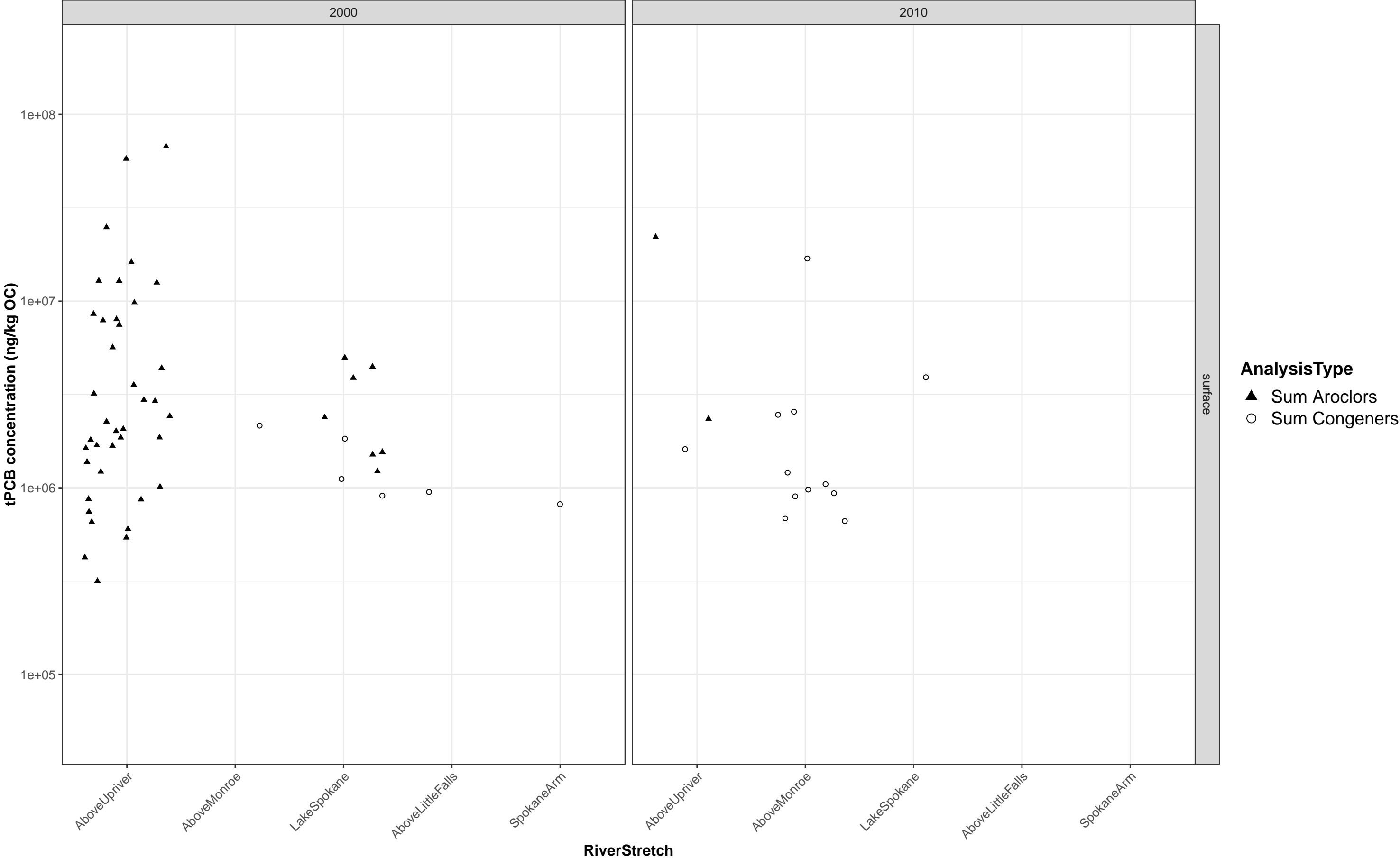
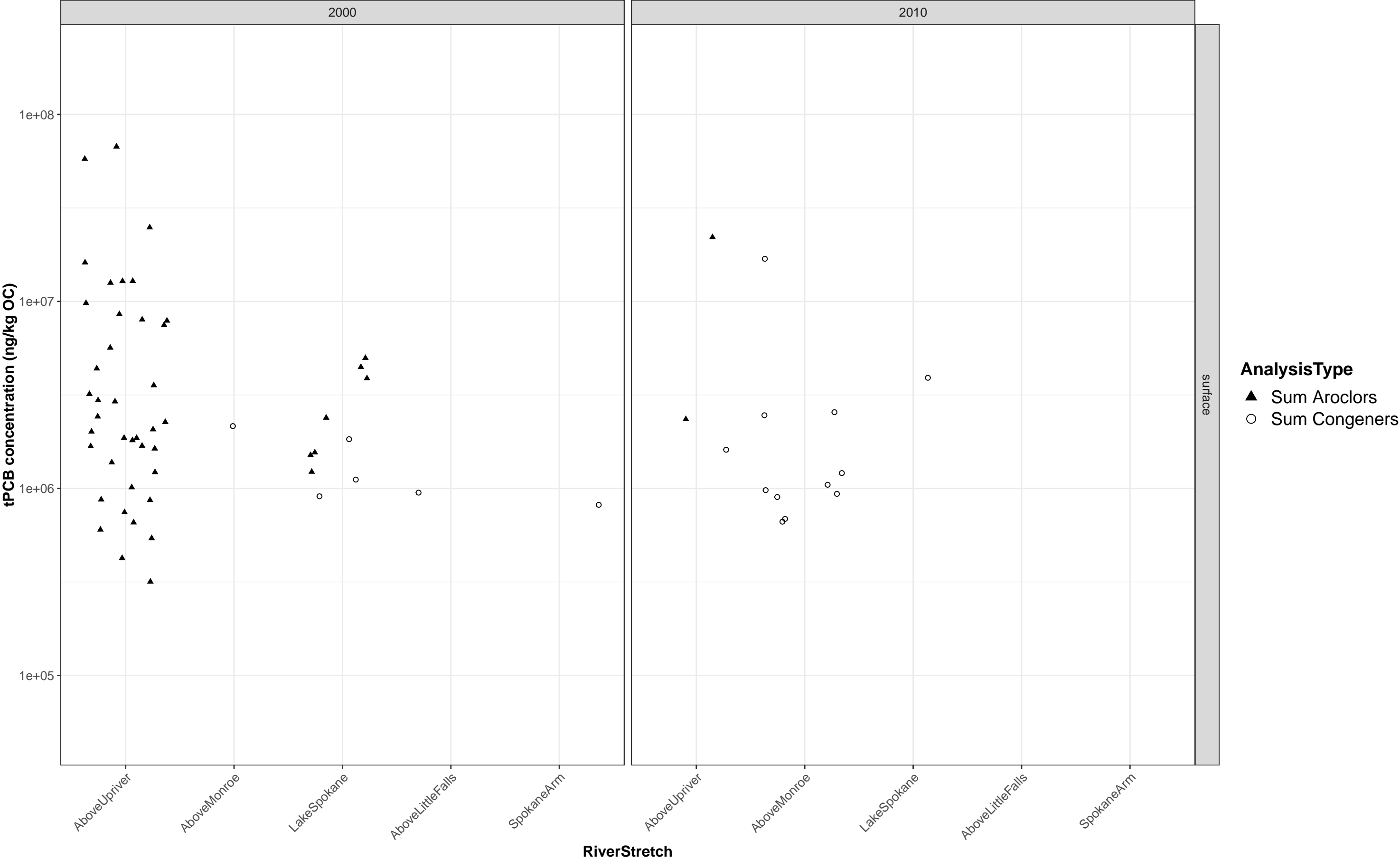


Figure 8F: Total PCB concentrations in sediment from the Spokane River (ng/kg OC) as a function of river stretch. Subset by key time periods (2000s and 2010s). Individual congener/Aroclor non-detects assigned full DL.



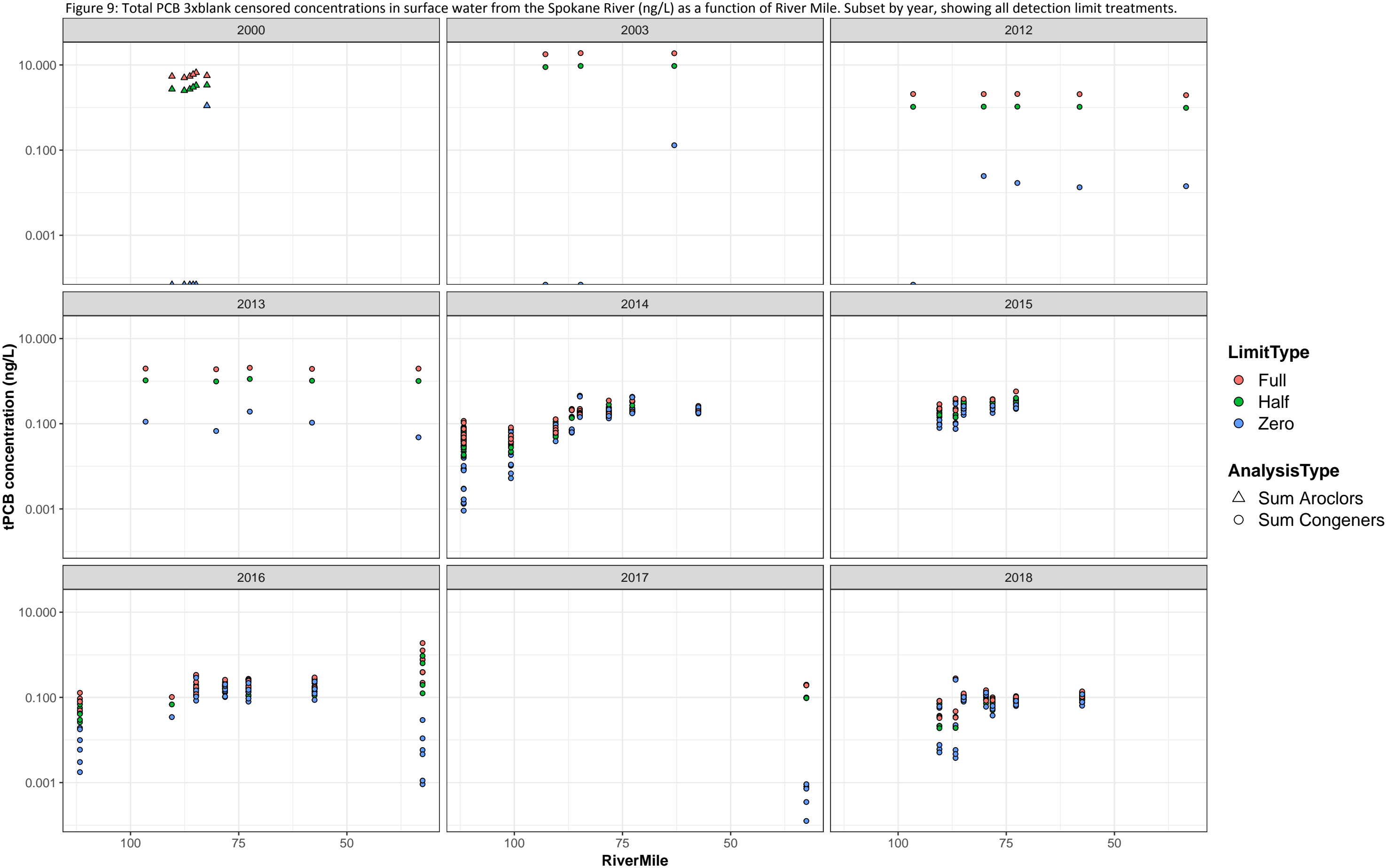
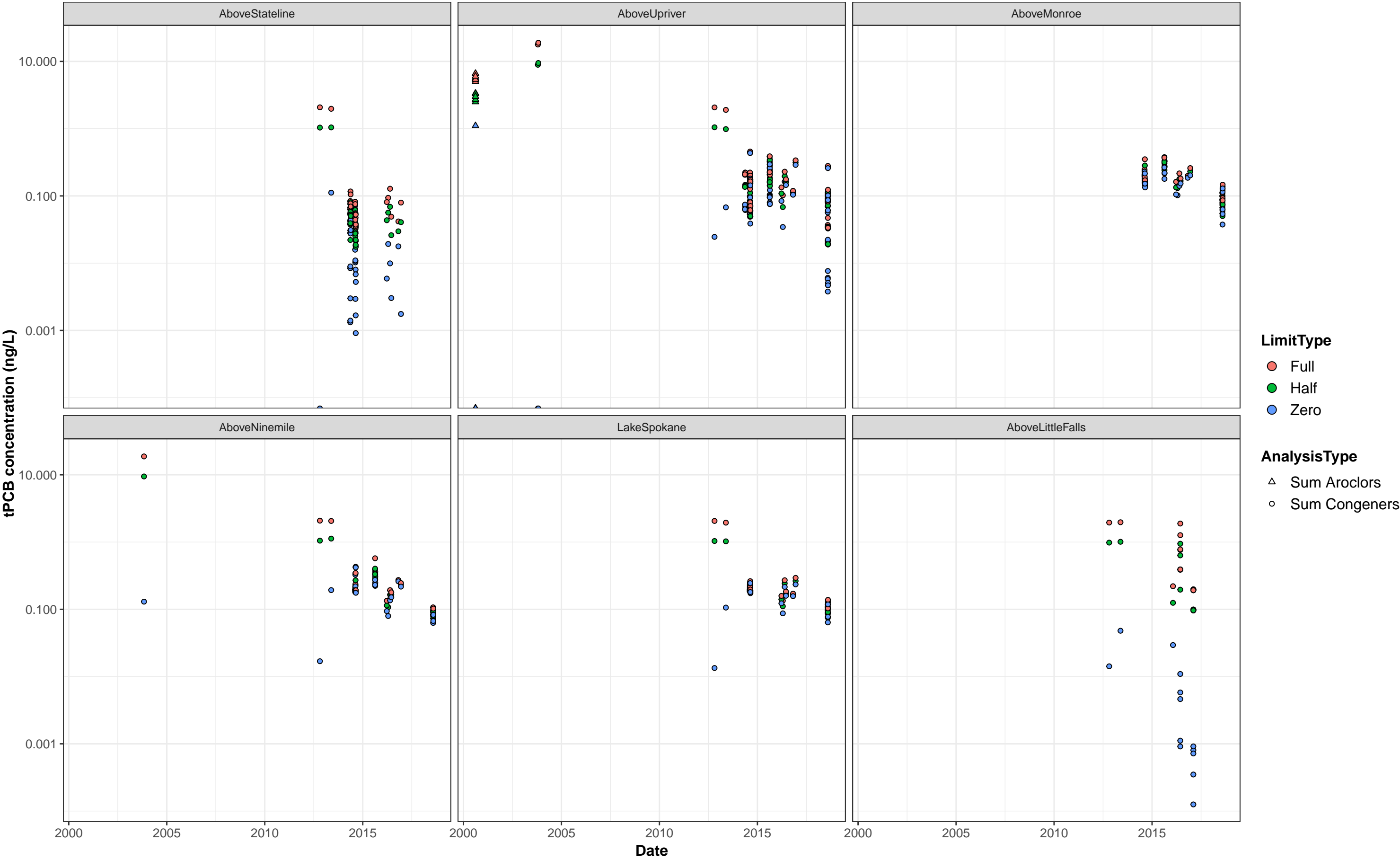
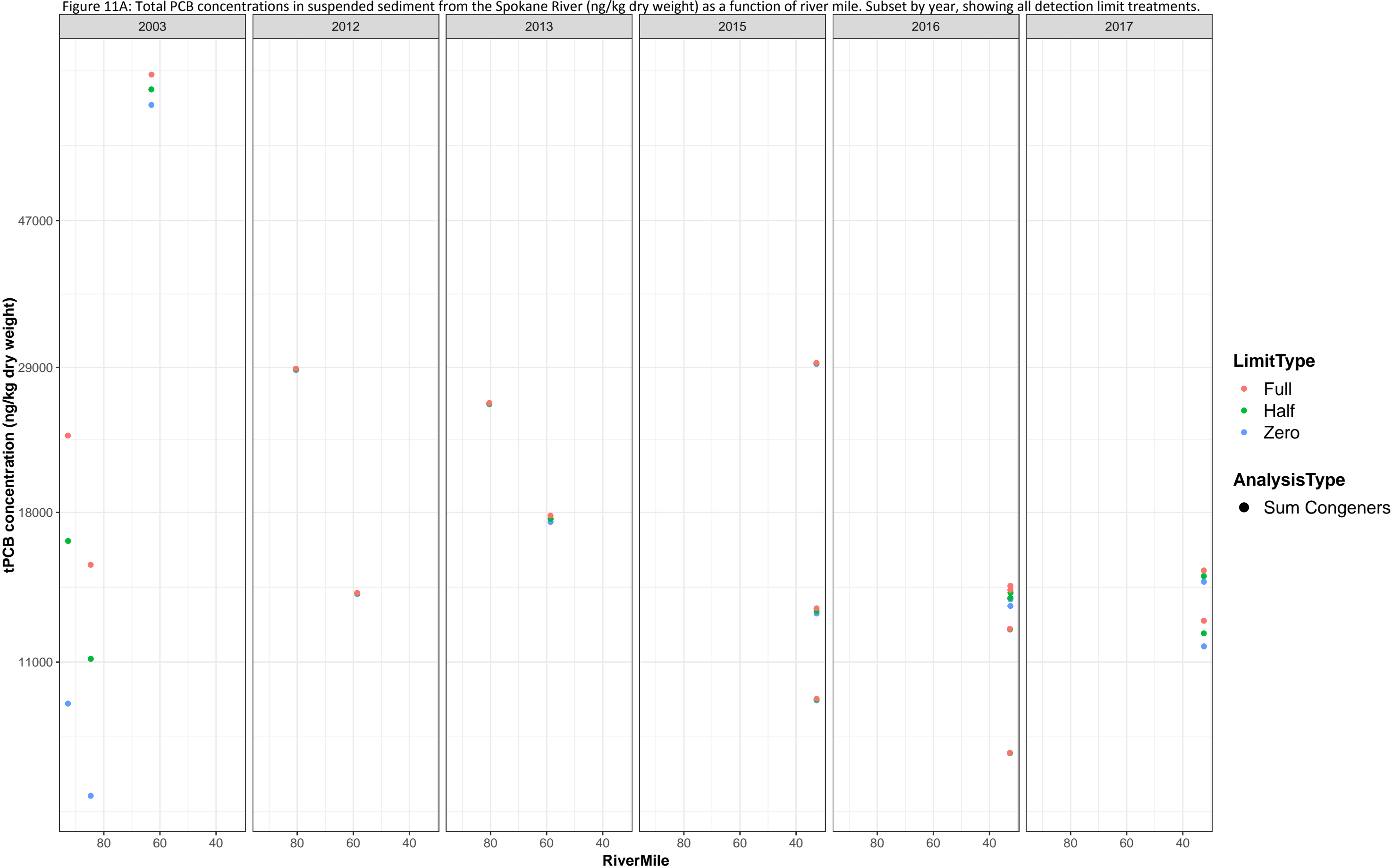


Figure 10: Total PCB 3xblank censored concentrations in surface water from the Spokane River (ng/L) as a function of year. Subset by river stretch, showing all detection limit treatments.





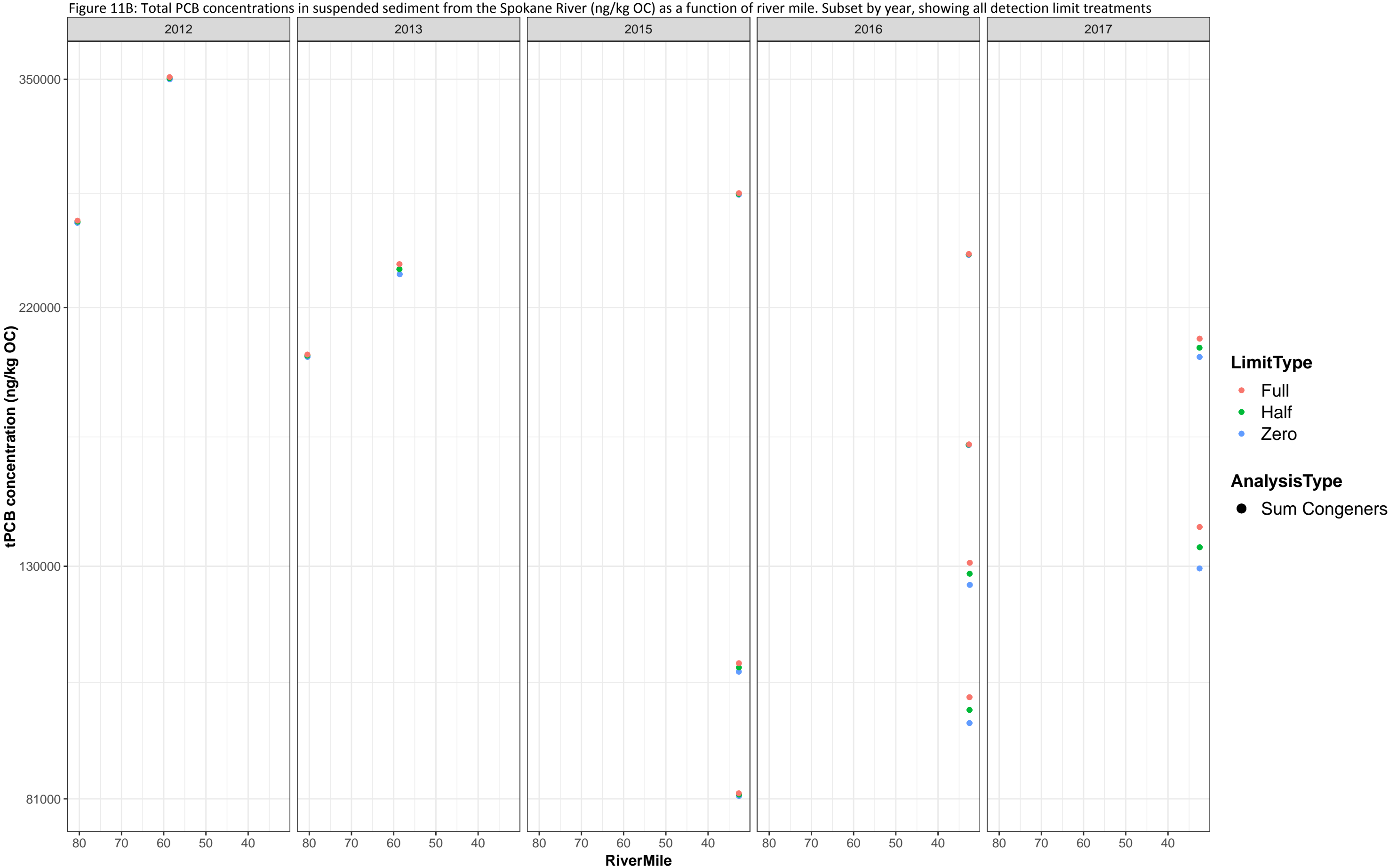


Figure 12A: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg dry weight) as a function of year. Subset by river stretch, showing all detection limit treatments.

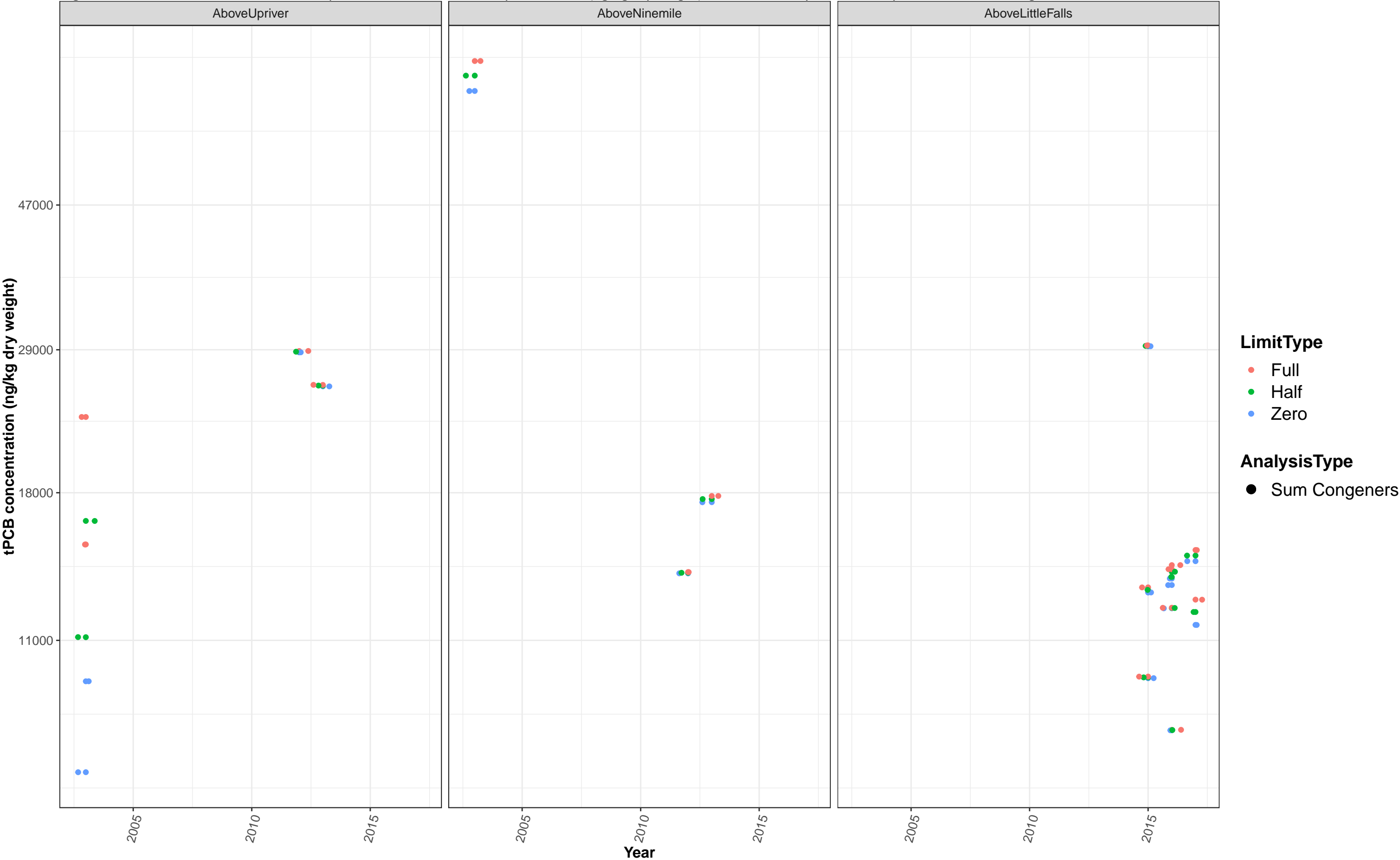


Figure 12B: Total PCB concentrations in suspended sediment from the Spokane River (ng/kg OC) as a function of year. Subset by river stretch, showing all detection limit treatments.

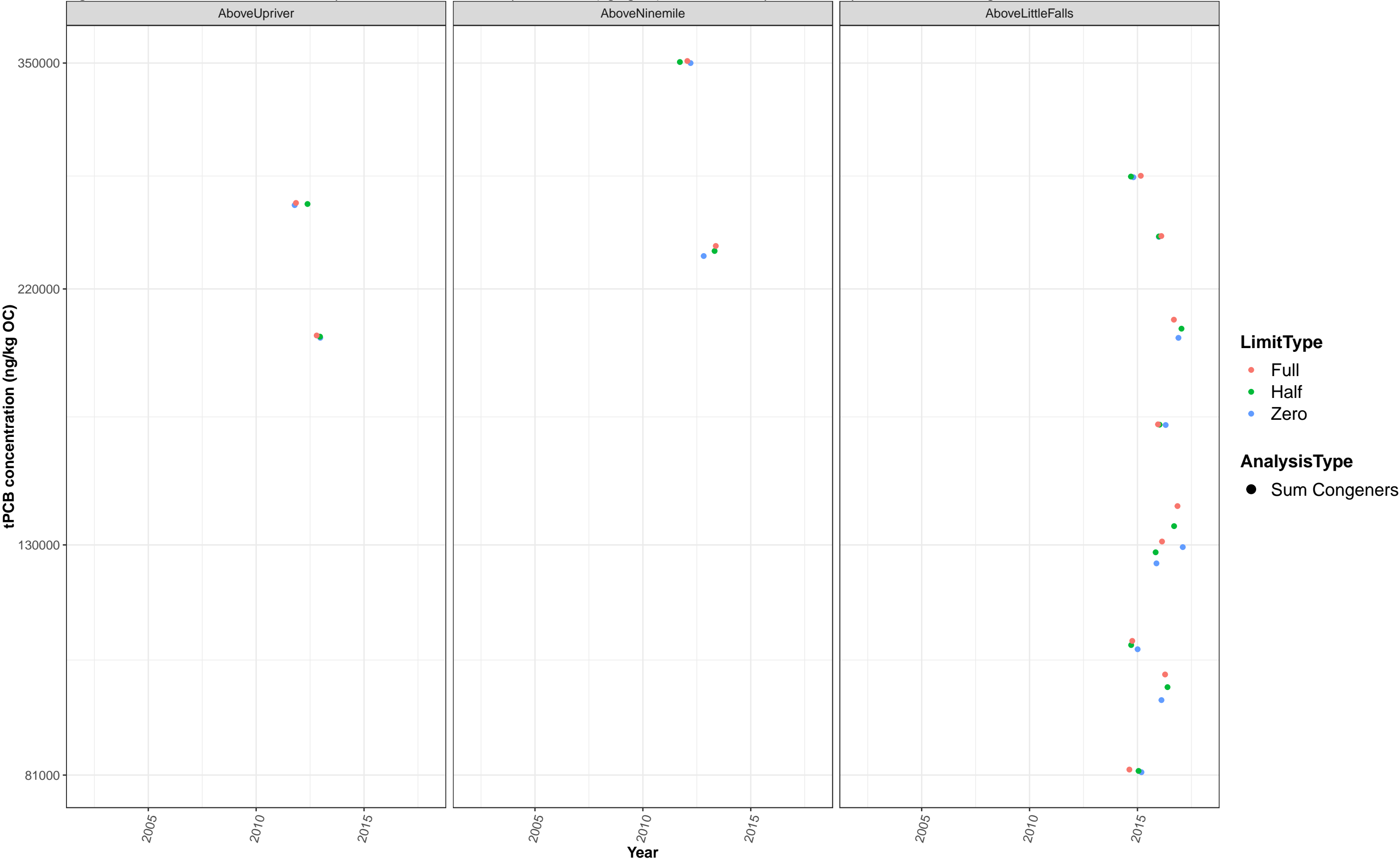


Figure 13A: Total PCB concentrations in biofilm and invertebrates from the Spokane River (ng/kg wet weight) as a function of river mile. Subset by year, showing all detection limit treatments.

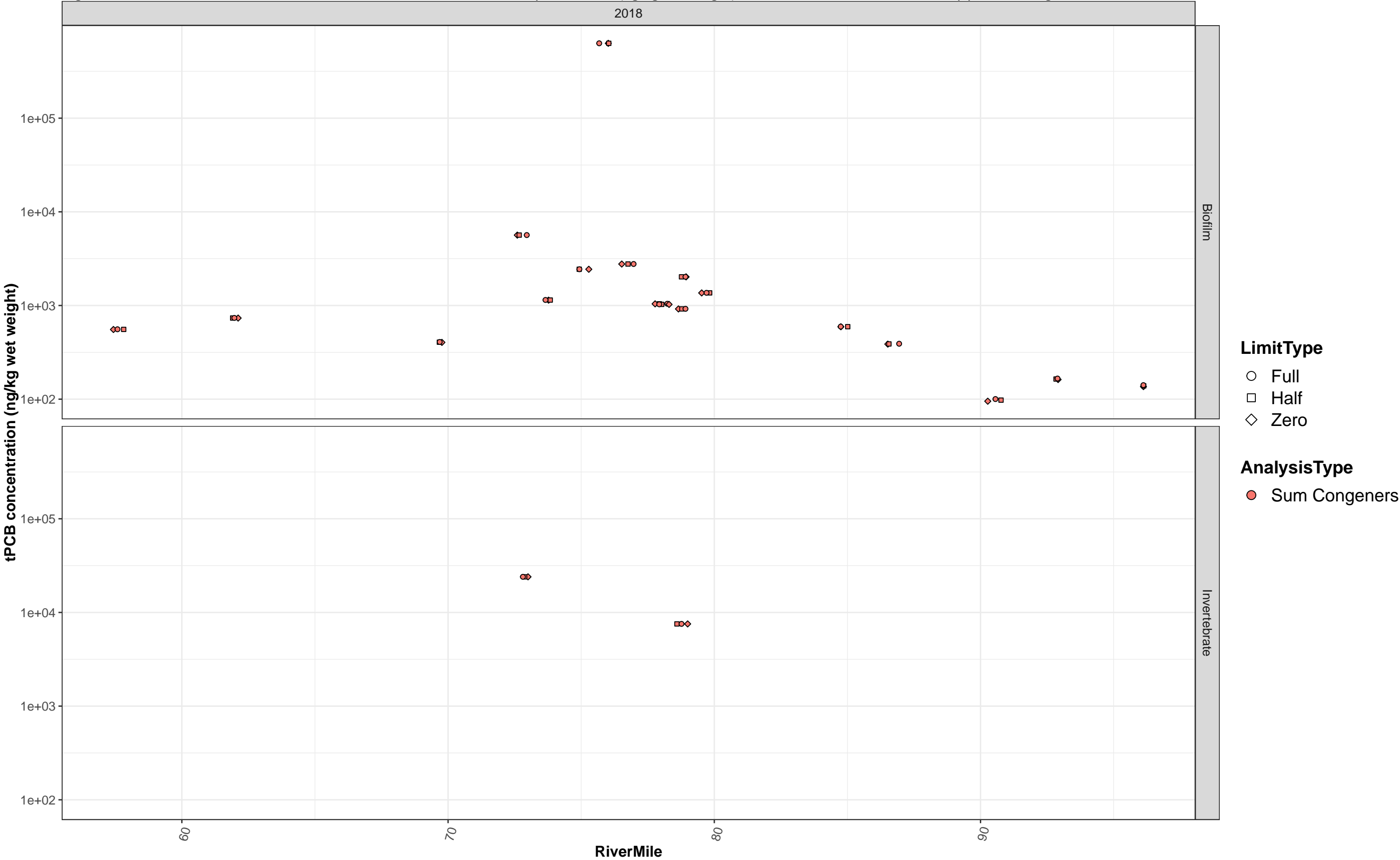


Figure 13B: Total PCB concentrations in biofilm and invertebrates from the Spokane River (ng/kg lipid) as a function of river mile. Subset by year, showing all detection limit treatments.

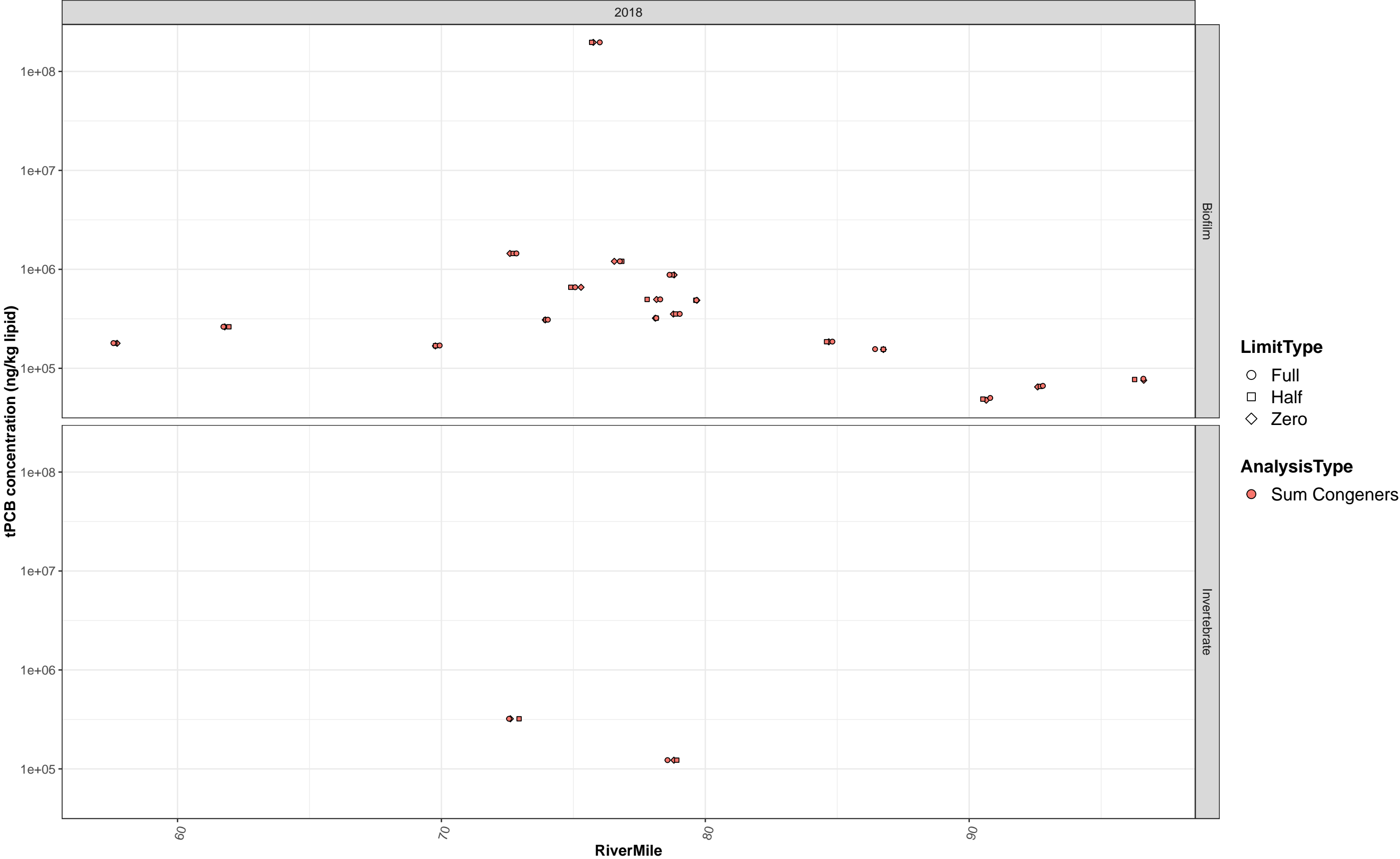


Figure 13C: Total PCB concentrations in biofilm from the Spokane River (ng/kg OC) as a function of river mile. Subset by year, showing all detection limit treatments.

